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THE
ETALS USED IN CONSTRUCTION:

IRON,—STEEL,—BESSEMER METAL,
ETC. ETC.

BY
FRANCIS HERBERT JOYNSON.
"

ILLUSTRATED.

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THE METALS USED IN CONSTRUCTION.

CHAPTER I.

CAST IRON.

(1.) THE metal known to us under the name of iron is one which possesses many properties which render it remarkably useful in the arts of construction. It possesses great strength, density, and hardness; and, under certain forms, is highly ductile and malleable: it possesses, moreover, the capability to be easily moulded and wrought into various forms, and to have a smooth surface and a high polish imparted to it. Although iron is met with in nearly all ore in organic substances, it is, for the purposes of art, obtained from what are called iron ores, or "ferruginous clay-stones." These are met with in various localities, and vary in the percentage of iron which they contain.

If this is less than twenty per cent. of the full weight of the ore, its reduction is not considered in practice profitable. The ores used principally in this country for the production of iron, are—first, the “blackband” or common “ironstone,” a “carbonate of iron,” which contains $61\frac{1}{2}$ per cent. of protoxide of iron, and $38\frac{1}{2}$ of carbonic acid ; second, “red hematite,” a “peroxide of iron,” a valuable iron, containing as much as $69\frac{1}{2}$ per cent. of ore ; third, “brown hematite,” a “hydrated peroxide of iron,” containing 80 per cent. of the peroxide of iron ; fourth, “magnetic iron ore,” a “black oxide” of iron (this is the most valuable of iron ores, containing nearly 72 per cent. of metal) ; and fifth, the “clay ironstones” found in connection with the Coal Measures, like the blackband, which contains from 24 to 35 per cent. of metal.

(2.) The following facts connected with the iron ores of Great Britain, compiled from a most exhaustive report by Mr Robert Hunt, F.R.S., will be usefully supplementary to what has been above given on the subject. The following table gives the mean average quantity of iron contained in the ores, which may be regarded as types of those which are employed in this country :—

	Yields of Iron per Cent.
1. Magnetic Oxide of Iron,	56·10
2. Red Hematite,	65·13
3. Brown do.,	41·40
4. Do. do. (oolitic),	35·60
5. Spathose ores,	40·95
6. Argillaceous ores (clayband),	30·68
7. Do. do. (blackband),	37·8
8. Mean average of all those ores, supposing them to be employed in equal quantities, . . . }	47·30

The argillaceous iron ores of the coal measures are used in far larger proportions than any of the others; and on an average it takes about two-and-a-half tons of the ore to produce one ton of the pig-iron. Remarks on the hematite ores, brown and red, will be found in an early portion of paragraph (1.) To these may be added the popular distinction between them, which is, that the red hematite ore produces a red streak, and the brown hematite ore a brownish-yellow streak, when they are drawn across the surface of unlazed pottery. At Froghall, near Cheodle, in Staffordshire, a remarkable calciferous brown hematite occurs, of which the following is an analysis, as made by Dr Percy:—

Sesquioxide of Iron,	52·83
Lime,	14·60
Magnesia,	5·70
Carbonic Acid,	18·14
Water combined,	4·75
Organic Matter	1·30

The following are Analyses of the Lincolnshire Iron Ore, as made by Mr J. Pattinson of Newcastle, and Mr J. D. Sollete of Hull :—

METALS USED IN CONSTRUCTION.

	Soft Upper Stone.	Small Yellow Ore.	Small Black Ore.	Orange Stone.	Spathic Ore.	Bottom Black Stone	Hard Spathic Ore
Oxide of Iron, . . .	92.34	81.12	62.71	75.28	66.25	64.50	28.50
Silica, . . .	5.16	2.14	5.97	5.02	...	14.50	1.07
Alumina, . . .	2.44	12.31	3.79	1.53	1.30	2.50	0.45
Lime, . . .	...	0.03	1.45	1.01	0.50	10.12	25.20
Magnesia, . . .	0.05	0.15	0.53	0.30	0.51	0.12	0.28
Manganese, . . .	...	4.25	0.20	0.46	4.52	0.04	...
Sulphur, . . .	0.01	...	...	...	...	...	...
Phosphorus, . . .	...	1.32	2.00	1.02	...	...	...
Carbonic Acid, . . .	...	...	...	...	27.12	8.12	34.50
Water, . . .	...	...	...	14.93	...	...	...
Metall. Iron per cent., .	64.75	56.75	43.90	52.70	48.	50.95	30.

Of the Oxfordshire oolitic iron ores found in the neighbourhood of Banbury and Woodstock, the following are analyses by Dr Percy :—

	Woodstock.	Banbury.
Peroxide of Iron,	44·67	3·19
Protoxide of Iron,	0·86	12·34
Protoxide of Manganese,	0·44	Trace
Lime,	0·29	34·82
Magnesia,	0·66	1·67
Alumina,	7·85	3·36
Phosphoric Acid,	0·55	0·26
Carbonic Acid,	6·11	31·92
Silica,	0·48	2·13
Water,	16·31	1·76
Ignited Insoluble Residue.		
Silica,	11·86	6·18
Alumina,	1·25	0·61
<hr/>		
Metallic Iron,	31·94	11·98

The following are analyses of a few of the iron ores the Cleveland district in Yorkshire, of which Mr Montagu remarks that, in the history of the iron trade, more remarkable development of any special industry can be rendered. Of this ore the same author remarks, that it “was deposited probably as an oolitic limestone, not very unlike the limestone deposits many coral reefs, interstratified with ordinary clay.

containing a large amount of the oxides of iron and organic matter. By their mutual re-action these would give rise to a bi-carbonate of iron which, in solution, percolating through the limestone, would remove a large part of the carbonate of lime, and leave in its place carbonate of iron."

	Cleveland.	South Bank.	Easton Nab.	Dogger Bed Grosmont.
Protoxide of Iron, .	39·92	43·02	43·35	22·30
Sesquioxide of Iron,	3·60	2·86	1·20	...
Protoxide of Manganese, . . . }	0·95	0·40	...	0·50
Alumina, . . .	7·86	5·87	9·88	2·10
Lime, . . .	7·44	5·14	0·58	11·80
Magnesia, . . .	3·02	5·21	5·35	3·96
Potash, . . .	0·27	...	...	...
Silica, . . .	7·12	7·12	7·65	...
Carbonic Acid, .	22·85	25·50	22·96	24·40
Phosphoric Acid, .	1·86	1·81	3·87	0·30
Water, . . .	2·97	3·44	9·14	3·20
Insoluble Matter, .	1·64	0·05	...	30·96
Metallic Iron, .	33·62	35·46	34·54	17·34

When it is recollected that the celebrated "steel irons" of Siegen, Styria, and Corinthia have always been produced from the spathose ores—"chalybeate," "sparry carbonite of iron"—we may join with Mr Hunt in expressing surprise at their neglect in this country—a neglect for which, he says, "it is difficult to

account." For years they were totally neglected, being worked chiefly along with lead ores, and thrown aside as mere worthless refuse. To Mr Charles Attwood, of the Tow Law Works, we are indebted for the introduction of these ores in the iron industry of the kingdom. At Weardale the spathic ore is often found associated with a brown ore—a hydrated oxide. The following analyses will show the composition of both of these ores:—

	Spathose.	Brown Ore.
Protoxide of Iron, . . .	49·97	...
Peroxide of Iron, . . .	·81	71·11
Protoxide of Manganese, . .	1·93	6·60
Lime,	3·96	·53
Magnesia,	2·83	1·90
Alumina, . . . . .	...	·40
Carbonic Acid,	37·20	·12
	—	—
Metallic Ore,	38·95	49·73

The character of the iron produced from these ores is of a marked kind, highly crystalline, and affording bar-iron of excellent quality. The composition of a description of iron which approaches in its properties the charcoal-irons of Germany and Sweden, should draw the attention of English iron-masters to it. A few analyses of the metallic iron obtained from them will be interesting:—

	German Spiegeleisen.	Weardale White Spiegel.	Swedish Iron.	Weardale Iron.
Iron, . .	82.11	96.775	95.27	99.510
Carbon, . .	4.77	2.092	4.02	.065
Silica, . .	.82	.882	.08	.140
Manganese, . .	11.12	0.21	.10	...
Sulphur, . .	.74	.229	.30	...
Phosphorus, . .	.13	...	.05	Trace.
Copper, . .	.31	...	...	...
	100.00	100.000	100.00	99.999

Desirous to make our remarks as complete an exposition as possible of the most recent researches into the metals employed in construction, we do the reader a service by placing before him the following tables of analyses of iron ores *in use*, for which we are indebted to an able paper by Mr Edward Riley, F.C.S., late of the celebrated Dowlais Iron Works, read before the Society of Engineers. After stating that the clay ironstones had, until recently, been almost exclusively used for the manufacture of iron until the discovery of the black-band ironstones, and that this latter ore was found in thick layers, three feet to four feet in thickness, while the clay ironstones only occurred in thin layers a few inches in thickness in the mine shale, this authority proceeds to say: "Before the introduction of railways

scarcely any other ores than these were used, as they are always found associated with the coal. Although much richer ores were known, such as the red hematite, from the difficulty of conveyance they were only used to a limited extent. On the introduction of the railway system the rich ores were largely imported, and not only increased the production, but diminished the cost of iron, enormous quantities of the red hematite being imported into Wales and Staffordshire from Lancashire and Cumberland, where the ore seams measure from 15 to 30 feet thick." The principal deposit of the "oolitic" ores (named in the Table No. 1) is in Cleveland in Yorkshire, where, in consequence of the discovery of this ore, these enormous iron works have been established. It is a mixture of green carbonate of iron with a little silicate of iron, and is found in immense beds of 18 feet in thickness, 15 feet of which can be utilised. The other oolitic ores are met with in Northamptonshire and Wiltshire, and a little in Oxfordshire and in Lincolnshire. While the Cleveland oolitic ore is dense and solid, those latter named are porous; they are all like the brown hematite hydrated peroxides. One feature which distinguishes the oolitic ores from the brown and the red hematites, is the high percentage of phosphoric acid

which they contain. The Elba ore named in Table No. 2 is described as a micaceous iron ore, from its structure being laminated like mica; it is an unhydrous peroxide of iron. The "spathose ore," known also as Spiegeleisen, Stahlstein, or Stedstine, and used on the Continent, is a white carbonate of iron, producing a peculiar description of iron containing a high percentage of manganese :—

Fig. 1.

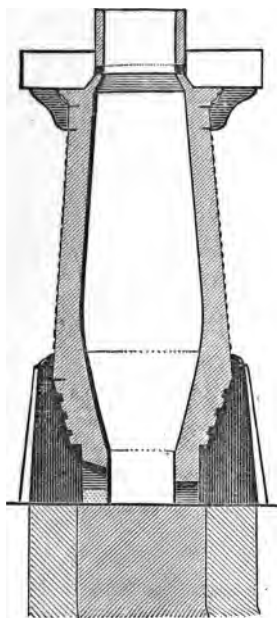


TABLE No. I.

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TABLE No. II.

	IRON ORES.								
	Magnetic Oxides.			Elba.	Whitehaven.		Cornish.		Lantrisant.
Silica, . . .	2.80	2.33	13.79	.34	5.78	21.85	36.33	25.97	34.40
Peroxide of Iron, . . .	63.15	67.78	52.02	99.36	93.35	77.56	51.87	69.38	59.05
Protoxide of Iron, . . .	13.23	29.85	22.80	..	..	..	..	..	..
Peroxide of Manganese, . . .	17.88	.05	.26	..	..	..	.43	..	.09
Alumina, . . .	..	..	..	..	.40	1.54	4.01	4.05	..
Lime, . . .	.57	.50	7.94	..	..	.53	.43	..	.25
Magnesia, . . .	2.34	.26	2.05	..	..	..	.17	.37	.28
Phosphoric Acid, . . .	..	..	..	.09	.12	.19	.49	.05	.14
Moisture, . . .	..	..	..	..	..	..	.80	..	.24
Combined Water, . . .	.48	.21	.31	..	..	..	5.80	..	6.14
Sulphur, . . .	..	..	.13	..	..	..	.03	..	.05
Iron, . . .	..	..	..	..	..	copper	.05	..	.04
	100.45	100.18	90.30	99.79	99.65	100.87	100.16	99.82	100.68
Metallic Iron,	54.49	72.04	54.15	69.50	65.30	54.29	36.30	48.56	41.30

(3.) The following is the author's description of the qualities of the iron made from the foregoing ores:—
 "This clay ironstone unquestionably made a very superior quality of iron. This was due partly to their containing no free silica, as sand or quartz; but the whole of the silica, or nearly so, existed in combination with silica as clay. Besides this, it contained a moderate amount of lime, magnesia, and a little potash, which, by the addition of a small amount of limestone, form a readily soluble flux. The ore, containing a little

phosphoric acid, made the iron work easily and not red-short. The tendency of the hematites was to make an iron of a siliceous character, as the ores generally combined quartz and no alumina, a very little and only traces of lime, magnesia, etc. The ore also being free from phosphoric acid, the iron was generally red-short. There are a few known hematites which are calcareous, but they are generally siliceous. The oolitic ores were distinguished by the high percentage of phosphoric acid that they combined, as a rule, and the "cold-short" nature of the iron made. The Cleveland ores contained an excess of alumina, which had the effect of making the crucible from the furnaces less fusible. This had been obviated by mixing siliceous ores with the oolitic, or in some cases by adding silica or sandstone to the blast furnace, for which there was a patent. This, however, required great caution. The Northamptonshire and Wiltshire oolitic ores differed much from the Cleveland. They contained an excess of silica, and made a pig-iron, containing both a high percentage of silica and phosphorus. Before the railway system was developed to its present extent, it was always considered that the ironstone should be carried to the coal; but, partly by increased facilities of communication, and partly by improved manufac-

ture, it has, in many cases, been found more advantageous to carry the coal as coke to the iron ore; and recently large works have been established to melt the ore *in situ* in Cumberland and Lancashire, and in Northamptonshire and Wiltshire. . . . In the Cleveland districts the supply of coal is brought from Durham, and it is only by the superior quality of the Welsh and Staffordshire coal, and its lower cost, that these works can at all compete in making bars with the Cleveland district. . . . When several kinds of iron ores are used, as is the case at the Welsh works, by the judicious mixture of them, any peculiarity of iron which an iron ore may produce may be much modified."

(4.) The impurities present in iron ores exercise an influence more or less deleterious on the quality of the iron produced, according to their kind and quality. The impurities of the sulphur and phosphorus are those which exercise the most deleterious influence. Where much sulphur is present in the ore, it produces in the iron the quality known as "red-shortness;" that is, the quality which gives the iron an undue degree of brittleness when red-hot. Too high a percentage of phosphorus renders the iron "cold-short;" or that quality which gives to it an undue brittleness when cold. The material of which the slag produced in the

furnace is formed, and which is called "gangue," and which is composed of quartz and clay, exercises also a very deleterious influence upon the iron produced.

We now come to describe the smelting of the ore. Previous, however, to this process being carried out, it is the practice in some districts to roast or calcine the ore, which is effected by keeping the ore mixed with a certain proportion of fuel, and setting fire to the mass. Calcining or roasting is for the purpose of rendering the ore more porous than it naturally is, by expelling the water and carbonic acid, thus rendering it more easily smelted.

(5.) The smelting of the ore, in reducing it to the condition of pig or cast iron, is performed in a furnace called the blast furnace. In fig. 1, p. 10, we give a section of one of the four furnaces at the Ormesby Iron Works, Middlesburgh, belonging to the Messrs Cochran & Co., and for which we are indebted to a paper on the "Construction of Blast Furnaces, and the Manufacture of Pig-iron in the Cleveland Districts," by Mr J. C. Beckton of Whitby, read before the Institution of Mechanical Engineers. From an able paper on "Machinery for the Preparation of Iron," in the *Engineer*, we take the following description of a blast furnace, and the mode of working it. As will

seen from the illustration in fig. 1, the blast furnace is formed of "two truncated cones united at their basis." The point of junction of these is, however, in some constructions, curved as in fig. 1. "The upper portion, called the cone or body, is in the interior lined with fire-bricks, which lining is again inclosed in a casing made up of broken scorizæ, or refractory sand, and separating the internal lining or shirt of the furnace from the external coating of fire-bricks; this is supported by a mass of masonry, composed of stone or common bricks. The opening at the top of the furnace, called the throat or trunnel-hole, is surmounted by a chimney, containing one or more openings for the convenience of charging the fuel, ore, and flux with which the apparatus is supplied at regular intervals. The lower cone, made of fire-brick, or a refractory material called fire-stone, principally obtained from coal formations, is known by the name of "the bosh." As this part of the arrangement is subjected to a very high temperature, it is of the greatest importance that the material it is composed of should be carefully selected, for the length of time during which the action of the furnace can be uninterruptedly carried on mainly depends upon the durability of the boshes. The two cones forming the body *boshes are united either by a curve or narrow c-*

l belt, to prevent the occurrence of a sharp angle, and at this end the edges are slightly rounded off, and a face is formed called the belly. The lowest division of the furnace is in shape a quadrangle, and is composed of large slabs of refractory sandstone, which are cemented together with fire-clay. This division is a little smaller at the bottom than at the point where it meets the boshes, and its angles are gradually rounded off; but this difference in size at its two extremities is, in many instances, so trifling that the hearth (as this part named) may almost be termed a quadrangular prism. The bottom of the furnace is composed of large fire-bricks, which are supported on a mass of masonry, and numerous channels are left open, through which any moisture from the brickwork may escape; while, in order to keep the whole building thoroughly dry, two arched galleries traverse the foundations, and intersect each other at right angles beneath the axis of the internal cavity of the furnace. Only three of the sides of the hearth are continued to the stone, which constitutes the bottom of the arrangement. The fourth is merely brought to a certain distance within that of the first, and is there supported by strong cast-iron bearers or girders, firmly fixed into the masonry of the walls. On these bearers rests a heavy block of sandstone, called

the tym. About five or six inches beneath the tym, also a little in advance of it, is placed a stone called dam-stone, which is in the shape of a prism. It is securely fixed by means of a strong piece of iron of a peculiar shape, covering its outer side, and called dam-plate. The part of the furnace beneath the tym is called the crucible, in which the fused metal is collected, till a proper quantity has been accumulated for tapping. The blast from the blowing machine is conducted into the furnace by means of the tuyers, which are fitted into holes perforated a little above the level of the tym, in the face of the hearth (opposite the dam) and its two sides. To save waste of time in workmen passing from one tuyer to another, it is usual to have four vaulted galleries constructed, which connect the various arches by which the tuyers and sides of the crucible are approached. In practice it is usual to build two or more of these blast furnaces side by side, and it is found advantageous, when the situation permits, to place them at the foot of a declivity, in such a way as will render it easy to connect their summits with the adjoining high ground by means of a bridge. By this arrangement the furnaces are easily supplied with the necessary ore and fuel ; but if, from the nature of the country, this method cannot be adopted, it is

either raised by means of an inclined plane and waggons worked by the engine of the blowing machine, or by a moveable platform raised by compressed air or hydraulic pressure. Generally, the tops of the furnaces are enlarged by a platform, as shown in fig. 1, and which, to prevent accidents, is railed round; and when the moveable stage is used, the ore, etc., is raised in iron waggons, which can be readily transferred to a continuation of railway on the platform of the furnace, conducting them directly to the throat where the waggons are tilted and their contents shot out. That the moisture may readily escape, and the brickwork be prevented from splitting through the pressure of confined watery vapour, the whole of the masonry constituting the exterior casing of the apparatus is traversed by numerous small channels, which greatly facilitate the drying of the mass. Stout iron bands, as shown in fig. 1, are likewise made, to bind the work strongly together. These bands are on the outside of the work, and are made to bind tightly by wedged keys or screws and nuts. These horizontal bands are also held together by long vertical bars, to which they are attached by loop-eyes or strong screw-bolts, and by this means great strength and solidity are communicated to the building. The most common height of these furnaces

is from 45 ft. to 50 ft., not including the chimney, which is from 8 ft. to 10 ft. in length, and frequently formed of only one course of bricks, strongly bound together by stout iron rings and girders. In some cases the chimneys are so firmly ironed that their surface is half covered with metal. Usually two doors are left on the opposite sides of the base for the introduction of the ore and fuel. A large annular plate of cast-iron protects and holds together the throat or trunnel-hole, and on it the foundation of the chimney reposes. The inclination of the boshes will depend on the nature of the cast-iron which it is desired to produce, as its quality appears to be greatly influenced by the slope which is given to this part of the furnace. They are commonly less sloped when very dark iron for the purposes of casting is manufactured than when grey iron for subsequent conversion into bars is required. The limit of this difference generally is about 5 deg., the usual angle formed by the sides of the boshes with the perpendicular being from 55° to 60° . For the erection of a pair of blast furnaces of 40 ft. in height, 32,000 common bricks for the outside masonry, and 80,000 fire-bricks for the refractory lining on the inside, are required. The blast must be regulated according to the amount of the metal required to be run down,

and the size of the furnaces. As a rough average, the power required to produce the requisite supply is 25-horse power each furnace, but the following will form the best guide:—1-horse power will produce $2\frac{1}{2}$ tons of metal weekly; and as a criterion as to the amount of air required, it may be taken as a fair average that 60 cubic feet per minute will produce 1 ton of metal per week.

“The blast is admitted into the hearth at a pressure which varies within considerable limits, according to the season of the year or the nature of the fuel employed. The air being more rarefied in summer than in winter, will contain in a given bulk a less amount of oxygen, and therefore a larger quantity is blown into the furnace to produce a similar result. But little pressure is used with very light and easily combustible fuels, such as the various kinds of charcoal; but when a very dense fuel, such as coke, is employed, the air requires to be more strongly compressed. The small charcoal-fed furnaces of the Continent are frequently blown with not more than half-a-pound pressure on the square inch; but this is more or less modified according to the nature of the charges with which it is supplied. The pressure for coke varies from $2\frac{1}{2}$ lb. to $3\frac{1}{2}$ lb. per square inch; but these numbers represent the extreme limits, the average

probably being between $2\frac{1}{2}$ lb. and 3 lb to the square inch."

(6.) The process of reducing the ore to the iron of commerce is as follows:—The ore being prepared and assorted, if of various kinds, and, if necessary, subjected to the preliminary process of roasting or calcining, as described in paragraph (4.) and the blast furnace having been put into operation, and brought up to the proper heat—all of which operations require the exercise of great skill on the part of the ironmaster—the ores are mixed with the "flux," presently to be described, and charged into the blast furnace in a proper quantity, and the fuel, coal, or coke thrown in over them. Another charge of ore is then put in, followed by a second supply of coal or coke, and these operations are repeated at the proper intervals. The intense heat of the furnace being kept up by the action of the blast, the products are—first, the iron, which is a carburet or carbide of iron, composed of pure iron and carbon; and, second, the clay and other impurities, which are more or less separated from it, and which float upon the top, being of lighter specific gravity than the iron, which, of course, descends to the bottom of the furnace, from which it is withdrawn at intervals, and run into rough moulds or channels made

in sand, and to which the name of "pig" is given—hence the name, "pig-iron." The clay or scoriæ in a fluid state are drawn off by a proper aperture previous to withdrawing the melted iron.

(7.) At the end of paragraph (4.) we alluded to the material called "gangue," with which almost all iron ores are in combination, and the presence of which creates a difficulty in the reduction of the ores, arising from its infusibility. To render it fusible, a flux, alluded to in the last paragraph, is mixed with the ore; this is carbonate of lime, or ordinary limestone, which, in its passage through the upper and heated portion of the blast furnace, parts with its carbonic acid, and becomes what is called caustic lime. This enters into combination with the silica and alumina present in the ore, forming a double silicate of lime and alumina, and, being fusible, allows the iron to pass through and descend to the bottom of the furnace. Here, if not for the high temperature, the iron, freed thus from its impurities, to a greater or less degree, would be presented in the form of an oxide, but, in consequence of the high heat, it is completely deoxidised, and the oxygen is replaced by carbon; hence the iron becomes a carbide of iron, which is the condition of what is known as cast-iron. The air is supplied to the blast furnace by means of a

blowing engine, and is either hot or cold according to the system of hot blast or cold blast is used. Previous to the introduction of the hot blast, coke or charcoal were the only fuels used, as by these only could the temperature be obtained necessary to fuse the gangue. By the introduction of the hot-blast—a discovery of James Beaumont Neilson, of Glasgow—much higher temperatures were capable of being obtained with the use of uncoked coal—that is, with coal in its ordinary condition—than with coke or charcoal used in conjunction with the cold blast. In the hot blast, the air in its passage to the blast or smelting furnace is passed through a series of iron pipes, heated to a high temperature in a special furnace, and enters the smelting furnace at a temperature ranging from 500° to 700° Fah. The effect of the hot blast upon the quantity of the iron produced by it has given rise to a discussion which is still maintained, and to which we shall afterwards refer; but whatever be the effect, there can be no doubt that the introduction of the hot-blast system has created quite a new era in the history of the manufacture of iron: it has not only increased the quantity produced, but cheapened it, and enabled some districts, as those of Scotland, where the native fuel formed bad coke unfit for blasting purposes, to com-

pete successfully with others where the fuel was of better quality. The arrangements of furnaces or ovens for heating the air for hot-blast furnaces are exceedingly numerous. The reader will find a large amount of information in connection with the subject in a paper read before the Institution of Mechanical Engineers by Mr Henry Marten, of Wolverhampton, under the title of "On the Construction of Hot-Blast Ovens for Iron Furnaces." From this paper, as given in the pages of the *Engineer*, we take the following figures, illustrative of an apparatus erected at the

Fig. 2.

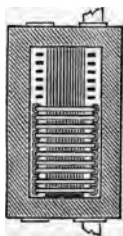
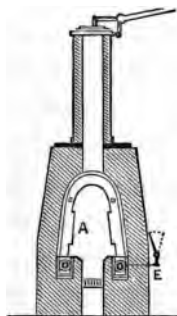


Fig. 3.



works of the Messrs Lloyds, Fosters, & Co. As will be seen from the illustration fig. 3, the furnace A is covered over, so to speak, with bent pipes, through

which the air is forced by the engine, the ends being connected with iron saddles resting upon iron rollers, to admit of the expansion and contraction of the pipes. Fig. 2 is the plan; fig. 3 the section.

(8.) From what we have said at the conclusion of the last paragraph, it will have been perceived that the quality of the coal exercises an influence of some importance upon the smelting process; of such importance, indeed, that, in the view of some authorities, the fuel "is even of greater importance than the ore." When used in its raw or ordinary condition, or mixed with coke, its merely mechanical condition was a matter of much importance; the better able to bear the weight of the surrounding ores and flux, the better for the purposes of the blast. The ash of the coal exercises also an influence upon the smelting process, for, being in close connection with the carbon of the coal, and subjected to a high temperature, its constituents are placed in a most favourable condition to be reduced, and therefore to be ready to act upon the ore more or less prejudicially. The following tables, by Mr Riley, give analyses of the blast-furnace coals and of their ashes:—

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ANALYSES OF BLAST-FURNACE COAL.

	WELSH.				STAFFORDSHIRE.	
	1.	2.	3.	4.	Coal.	Coke.
Carbon, . .	89.50	88.13	87.62	82.60	76.32	85.14
Hydrogen, . .	4.37	4.51	4.34	4.28	5.18	.78
Nitrogen, . .	1.25	1.41	1.13	1.28	1.38	...
Oxygen, . .	3.14	2.94	2.53	3.44	10.74	1.24
Sulphur, . .	.54	1.01	1.06	1.27	1.01	2.16
Ash, . .	1.20	2.00	3.32	7.18	5.37	10.68
	100.00	100.00	100.00	100.00	100.00	100.00

ANALYSES OF ASHES OF BLAST-FURNACE COAL.

	1.	2.	3.	4.	
Silica, . .	35.73	24.18	37.61	39.64	*1. Dowlais upper
Alumina, . .	41.11	20.82	38.48	39.20	4 feet coal.
Peroxide of Iron,	11.15	26.00	14.78	11.84	2. ,, Ras Gas.
Lime, . .	2.75	9.38	2.53	1.81	3. ,, Bargoid Big
Magnesia, . .	2.65	9.74	2.71	2.58	Coal.
Sulphuric Acid,	4.45	8.37	.29	...	4. ,, Torno Yard
Phosphoric Acid,	.99	.21	2.00	3.01	Coal.
Sulphur, . .	...	.14	...	...
Iron, . .	...	.24	...	...
	98.83	99.08	98.40	98.38	* These Nos. refer to both tables, and allude to the same coals.
Metallic Iron,	7.80	18.58	10.30	8.28	

Before dismissing the subject of iron ores, we must notice what is likely to turn out to be a very important

source of superior iron, namely, the titaniferous iron-sand recently discovered to exist in large quantities in New Zealand. Messrs Hipkins & Sons, of West Bromwich, were the first, we believe, to experiment with this substance, and with remarkably striking results. Since then, other firms have tried it, and with results as satisfactory. The iron obtained from this titaniferous iron-sand is stated to be "unprecedentedly fine," and it is worked or obtained from the ore with such facility that a "heat" of it can be puddled in an hour—just one half the time that the usual process of puddling occupies—and that the loss of iron involved in the process is only one-fourth of that usually met with. It is well known that a small quantity of "titanium" improves the quality of steel—a fact, the knowledge of which is due to the researches of Mr Mushet; but although the remarkably fine quality of iron produced from this New Zealand iron-sand is due, doubtless, to a certain extent, to the presence of this substance, it is probable that the entire absence from the sand of the objectionable substances of sulphur and phosphorus is the chief cause of the fine quality of iron obtained from it. This iron-sand of New Zealand contains from 9 to 13 per cent. of titanium *but the titaniferous iron ores, or what is call*

"ilmenite," found to exist in enormous quantities in Sweden, Norway, Russia, Canada, and elsewhere, are much richer in this oxide, having from 30 to 40 per cent. of it in their composition. They are rendered capable of being much more cheaply obtained than the iron-sand of New Zealand. It is true that there are great difficulties in the way of reducing the ore from the above-named ores possessing so high a percentage of titanium; but these will, doubtless, in time be overcome, although at present the mode of utilising them by mixing them with other ores is more the object sought to be attained by our manufacturers than that of smelting them by themselves.

(9.) As stated in a previous paragraph, the smelted iron from the blast-furnace was run off into the form of oblong moulds, which are termed in the trade pigs. The pig-iron of commerce is divided into certain numbers or classes, according to their quality, the numbers ranging from 1 to 6,—Nos. 1, 2, and 3 being classed and known as "foundry-iron;" Nos. 4, 5, and 6 as "forge-iron." The qualities of pig-iron vary very much according to the proportion of their constituents, and the impurities (as sulphur and phosphorus, etc.) which they contain; but they are all combinations of pure metal or iron with carbon. The most eminent

metallurgists, headed by Karston, maintain that the carbon exists in cast-iron in two forms,—one combined chemically with the iron, forming what is called a carbide of iron; the other mechanically combined, the combination being termed graphite. According to some authorities, the graphite is seen by the aid of a strong magnifying lens in newly fractured cast-iron in the form of scales, which give the glistening appearance which iron has when having much graphite in its composition. Other views are held on the subject. Mr William Crossby, F.R.S., who has devoted much attention to the subject, maintains that carbon is chemically combined with the iron, and that he has not been able to discover the scales of graphite above referred to. The so-called scales, he believes, if carefully examined, “will be found to be made up, not of iron and graphite, but of crystals aggregated together, and containing carbon and iron chemically combined.” Those who wish to pursue the subject further will find Mr Crossby’s paper *in extenso*, together with other papers bearing upon it, in the volume of “Engineering Facts and Figures” for 1863, published by A. Fullarton & Co., Edinburgh and London.

(10.) As stated in last paragraph, the general opinion *amongst* metallurgists is, that carbon exists in cast-iron

in two forms, chemically and mechanically combined, the mechanical combination forming what is known as graphite. Cast-iron is of two kinds, the "grey" and "white," the "grey" showing, when fractured, a granular appearance more or less distinct. It is soft and easily melted, and it contains a large percentage of carbon, not chemically combined, but forming graphite, as named above, and the presence of which imparts the grey colour. The "white" iron is hard and brittle, requires the highest temperature to fuse it, and, when fractured, presents, not a granular, like grey iron, but a laminated crystallised glassy appearance. The pig-iron known as "No. 1" abounds in this so-called graphite, and it is to its abundance in it, and in irons of this class—of which it forms the extreme example—that the soft fluid and easily melted character is owing, the excess of the suspended graphite mutually affecting, as it is supposed it does, the tenacity of the iron, by separating the various crystals, and thus reducing the cohesive attraction of the particles. From the properties above noted of cast-iron "No. 1," it is much used in the foundry for casting small and ornamental articles, where much strength is not required, but where an easily running metal adds to the sharpness of the casting. It is also used for adding to less

easily melted irons, as those of "No. 2" and "No. 3." These "Nos." contain less carbon than "No. 1," and are also harder, stronger, and more tenacious. While the specific gravity of "No. 1" varies from 6·9 to 7·2, that of "Nos. 2 and 3" vary from 7· to 7·5. By mixing "Nos. 1, 2, and 3" in various proportions, a great variety of what are technically called "makes" of iron are produced in a wide range of degrees of hardness, from the fluidity of "No. 1" up to the hardness of, and brittleness which characterises the, "No. 4," now to be noticed. This iron is a "white" iron, contains little carbon, is of a crystalline character, and requires a high temperature to melt it; its chief use in the foundry being to mix with the softer Nos. The same remarks apply, more or less modified, according to circumstances, to the "Nos. 5 and 6." "No. 3" is much used in combination with "No. 1," and what is called "scrap-iron," for the purposes of heavy castings. Where articles are required to be strong, and yet easily worked with the chisel and file, as in the case of worked wheels and the like, "No. 3" is used alone or in combination with good soft scrap-iron. This "scrap-iron" denoting, as its name does, that it is made up of scraps obtained from a wide variety of sources, varies, as may easily be supposed, very much in quality, ac-

cording to the material from which it is obtained. Although the file and the chisel afford the truest means, in the hands of a skilled person, to ascertain the quality of scrap-iron, still, as a general rule, small and ornamental castings will yield soft iron—those of a large size, as wheels, being hard, while the largest sized castings, as girders and the like, are usually of the hardest metal. Scrap-iron is cheaper than new “pig-iron,” and is, of course, for this reason, if for no other advantage to be obtained by its use, availed of largely by the founder for mixing with new iron.

(11.) From what we have already given as the different qualities of iron, it will be perceived that one of the great objects of the founder is to combine the various “Nos.” in such proportions as will yield a “make” calculated to give the castings formed from it the properties it is desirous they should have. Each founder is found to have his own notions on this mixing, and the result consequently is, that a vast number of recipes or mixtures are to be met with, each of which is highly esteemed by its proposer. The fact is, that in other branches, so in this, much depends upon individual skill and knowledge of the properties of the material operated with. Without going deeply into this department, the following remarks on “mix-

ings" for foundry purposes will answer all the practical purposes this section has in view. "Nos. 1 or 2" Staffordshire or Scotch may be used for small and ornamental castings; "Nos. 1 and 2" Welsh having much less carbon, are rather too hard to be used for this class of work. Where the castings are very fine, the addition of a little arsenic will give the requisite degree of fluidity to the iron; but, as a rule, "No. 1" of Scotch iron will be found all that is required for them. A mixture of "Nos. 1 and 3," or of "No. 1," with a small proportion of scrap-iron, will do for machine work, which requires to be strong and also tenacious, so as to resist shocks. For girders, bressummers, &c., a mixture of "No. 1" Welsh—this is better than "No. 1" Scotch or Staffordshire—with "Nos. 3 or 4;" or "No. 1" Welsh, with a large quantity of hard scrap of good quality. For columns, pillars, &c., and castings submitted to compressive strains, a mixture of "No. 1" Welsh, with a greater proportion of the "Nos. 3 and 4" than is used in castings for girders. "In all castings," says a good practical authority, "where there is a considerable body of metal, a harder mixture may be used than in the case of smaller castings, . . . and the founder need only exercise his *judgment* in the selection of iron for the cupola, &c."

guided as well by the cost of the iron as by its quality, and having as great a variety of irons as possible, as it is generally admitted that it is beneficial to mix a number of different 'makes' of iron in the absence of getting the right quality required direct from the furnace, an object not often gained in those days of hot-blast iron." The allusion here made refers to the fact, that in some cases, more especially where the cold-blast system is in use, an assortment of irons may be put into the smelting furnace so as to produce at one operation the right quality of iron desired, the comparative low temperature of the cold-blast furnace aiding this process better than the high temperature of the hot-blast furnace.

(12.) The subject discussed at the end of last paragraph brings us to that alluded to in a previous part of this work, namely, the influence of the hot-blast upon the quality of the iron produced by it. Opinions are very contradictory on this point; one great authority declaring decidedly that hot-blast is unquestionably inferior to cold-blast produced iron, while other as eminent authorities consider that, in some cases, it improves the quality, although in others they admit that it injures it. Messrs Hodgkinson and Fairbairn, in a report on the subject to the British

Association, state that it is rendered exceedingly probable that the introduction of a heated blast in the manufacture of cast-iron has injured the softer irons, whilst it has frequently modified and improved those of a harder nature; and considering the small deterioration that the irons of quality No. 2 have sustained, and the apparent benefit to those of No. 3, together with the greater saving effected by the heated blast, there seems good reason for the process becoming so general as it has. The immense saving effected in fuel is a great argument for the use of the hot-blast process, for by it coal is now used which, under the cold-blast system, would have been worthless. The subject of the influence of the hot-blast upon the quality of the iron has not been investigated with the closeness and accuracy which the vast interests involved in the iron interests assuredly demand. A writer in the *Mechanics' Magazine* attributes the inferiority of hot-blast iron (where it is avowedly inferior) to the presence of "cinder-iron" in it. This cinder-iron is obtained from the cinders or refuse of the puddling-furnace, and which contains a large percentage of iron combined with the impurities which have been worked out from the good iron in its conversion to wrought iron. "The power," says the

writer, "given by the hot-blast in extracting the iron from amongst these impurities has greatly increased the production, but the produce is rendered very inferior by an admixture of this material. . . . We do not assert that the hot-blast injures the quality of the iron. . . . Its precise effect has not been ascertained with precision. But we have seen that the hot-blast may be used to extract iron from any material from the best to the worst. The cold-blast can only be applied to the best ore and fuel; it cannot be used to make 'cinder-iron;' and thus the very name of 'cold-blast iron' is to some extent a guarantee as to its quality. The introduction of the hot-blast has thus been a great benefit as regards *quantity* of produce, but as regards *quality* it has offered facilities for 'scamping' the work, of which, unfortunately, too many have availed themselves. The hot-blast has also been the means of permitting the ironmasters to use raw or uncoked coal instead of the desulphurised coke. It is evident that more impurities are liable to be worked up with the iron when raw coal is employed." There can be little doubt as to the correctness of the above opinion as to the presence of "cinder-iron" in hot-blast iron being one of the chief causes of such inferiority, as any sample of it may be proved to pos-

sess ; for the impurities in "cinder-iron" are so great that they are calculated to deteriorate the value of any iron, however good, with which they may be mixed. The hot-blast iron may be considered as a process not only calculated to give quantity, and therefore cheap, but, if honestly used, a good quality of iron. The probability is, that efforts will be made—as indeed they have been made—to purify the iron obtained from cinders, which will be a move in the right direction. The effort, if successful, will undoubtedly pay, for many samples of cinders are found to contain as much as from 25 to 50 per cent. of iron, and vast heaps of it are at the disposal of many a manufacturer. One striking feature of the practical science of the day is the attempts which it has made, and is making, —and in some instances with striking success—to utilise the waste products of our manufactures: we hope, therefore, soon to see the day when the stores of iron hid in the mass of cinders will be obtained from them. A large amount of most practically useful matter in connection with iron will be found in the Report of the Royal Commission appointed to inquire into the employment of iron in railways. From this we take the following digest *of the evidence* given by the leading men of the

day on the subject of "Qualities and Mixtures of Iron."

The use of the *hot-blast* in the manufacture of iron, it is stated by Mr Glynn, does not of itself make iron better or worse, but by its means materials otherwise intractable, yielding alloys of iron, may be smelted instead of ores yielding purer metal. Mr Morris Stirling has not found any distinct difference between the chemical constituents of hot-blast and cold-blast iron, but, apparently, there is more carbon in the hot-blast iron, and graphite is more commonly to be seen on the surface of No. 1 hot-blast than on cold-blast iron. Mr Charles May considers that, by the use of the hot-blast, the quantity of carbon which can be combined with the iron is increased. Mr Hawkshaw and Mr Fairbairn consider hot-blast iron weaker than cold-blast. The latter gentleman and Mr Stephenson state the use of the hot-blast renders the metal very fluid; and Mr Glynn says that its use is to produce in large quantities, and at a cheap rate, a soft fluid metal to be employed in light castings, and that, in that respect, he considers the invention to be of great public benefit as enabling Scotch ironmasters to use a new kind of ore, which, though of a weaker character, further experience may enable them to purify and improve.

At the same time, the hot-blast is essential for smelting the ironstone from South Wales with anthracite coal, and the metal yielded is of the strongest character. Mr Glynn and Mr Stephenson state that generally hot-blast iron is dark-grey in colour, and very fine in the crystal; but it appears to be universally agreed that there is no certain method of distinguishing hot-blast from cold-blast iron. Mr Rastrick states that the temperature of the hot-blast at the Gartsherrie furnaces was 680° Fahrenheit.

Mr Stephenson does not attach much importance to the variation in strength of different sorts of iron, but considers that, taking the average of irons generally throughout the country, there is a proximity to a uniform standard. He concludes, from a series of experiments made by him for the High Level Bridge at Newcastle, that hot-blast iron is less certain in its results than cold-blast; that mixtures of cold-blast are more uniform than those of hot-blast; that mixtures of hot and cold blast give the best results; that simple samples do not run so solid as mixtures; that simple samples sometimes run too hard and sometimes too soft for practical purposes. Mr Rastrick would prefer making girders of forge-iron. Mr Hawkshaw would use the Lowmoor iron.

It is, however, generally admitted that mixing irons from different parts of the country produces the best castings, and since the object in mixing them is to obtain the proportion of carbon to iron which gives the greatest strength combined with the required degree of fluidity, the exact proportion will be regulated by the appearance of the fracture of the several irons. Mr Morries Stirling states that No. 1 hot-blast iron, mixed with No. 3 cold-blast, will give the right proportion of carbon ; but that if iron containing that proportion could be obtained at once from the blast furnace, it would be very superior. Mr Charles May, however, observes that the strength of cast-iron depends upon the bulk into which it is to be run, as well as upon its constituent parts, and that the art of the ironfounder consists in his ability to produce the required amount of strength, without any very definite knowledge upon the subject, either chemical or mechanical. Mr Fox considers a very good mixture for girders to be cold-blast Bluearm two-thirds, and of the hot-blast Scotch, two sorts, from the blackband and the red hematite ores, one-third. Mr Grissell considers the use of old scrap-iron to be of immense value, and would use Scotch iron called blast Welsh,

and old scrap. Mr Fairbairn names as the best mixture, independently of price—

	Per Cent.
Lowmoor, No. 3	30
Blaina or Yorkshire,	25
Shropshire or Derbyshire, No. 3,	25
Good old Scrap,	20
	<hr/>
	100

Mr Glynn names one-third strong iron from South Wales, and two-thirds of the more fluid metal of Yorkshire, Derbyshire, and Shropshire. Mr C. Fox, Mr Grissell, and Mr Charles May, however, all concur in stating that mixtures of iron practically depend very much upon the commercial question of cost; and it is generally admitted the engineers have no guarantee that the mixture for which they may have stipulated in a contract shall be that used by the founder. Hence Mr Fox recommends that engineers, in contracting for a number of girders, should stipulate that they should not break with less than a certain weight (leaving the mixture to the founder), and cause one more than the required number to be cast. The engineer might then select any one to be broken, and if it broke with a less weight than had been agreed upon, the whole should be rejected. Mr Glynn considers that the strongest

castings are those cast from the air furnace in dry sand, and that castings in loam are stronger than those in open sand. The metal is more dense and more free from impurity when cast upright. Mr Fox and Mr Fairbairn also prefer the air furnace. The following analyses of pig-iron by Mr Riley will be useful as showing the constituents of various qualities :—

ANALYSES OF GREY PIG-IRON FROM THE OOLITIC IRON ORES,
SILICIUM, SULPHUR, AND PHOSPHORUS ONLY DETERMINED.

	Silicium.	Sulphur.	Phosphorus.	
No. 1, .	4·717	·036	·807	Foundry Iron.
No. 2, .	3·659	·077	·917	
No. 3, .	3·909	·096	·908	
No. 4, .	3·140	0·196	·724	Forge.
No. 5, .	2·257	·160	·926	
No. 6, .	2·197	·248	·898	

GREY PIG-IRON FROM OOLITIC ORE,
(DIFFERENT DISTRICT FROM THE ABOVE.)

No. 1, .	3·21	·044	1·806	Foundry Iron.
No. 5, .	2·67	·081	1·853	Forge.

WELSH PIG-IRON.

	1.	2.	3.	4.	5.	6.
Silicium, . . .	2·16	2·22	1·96	1·21	1·14	1·09
Carbon, . . .	3·14	3·05	2·90	2·71	2·25	2·37
Iron, . . .	94·56	94·34	95·39	95·10	98·87	95·58
Phosphorus, . .	·63	·63	·63	·64	·82	·76
Manganese, . .	·50	·33	·23	·14	·17	·22
Sulphur, . . .	·11	·09	·04	·46	·77	·73
Nickel and Cobalt	·05	·07	·04	·03	...	...
	100·15	100·73	101·19	100·29	100·02	100·75

No. 1, ... No. 5 Furnace Cold-blast Grey Mine Pig-iron.

No. 2, ... Do. Hot-blast do. do.

No. 3, ... No. 5 Do. Cold-blast Mottled.

No. 4, ... No. 5 Do. Cold-blast White.

Nos. 5-6... White Forge Common Pig-iron.

By referring to the above analyses, from Nos. 1 to 6 in the first of the above tables it will be observed that "the percentage of silicium is directly as the quality of the pig, being the highest in No. 1 and lowest in No. 6; whereas the sulphur is inversely as the quality of the pig, being the lowest in No. 1 and the highest in No. 6. The phosphorus is a constant quality. The samples of pig analysed were made from the same materials. (See second Table, Welsh Pig-iron). The carbon does not differ very materially in quality in

grey iron, but as you get on to mottled and white, the carbon then becomes either partially or wholly combined with the iron ; whereas in very grey iron the carbon all exists as graphite." Although, from what has been said in paragraph (9.), considerable doubt exists as to the points involved in the chemical combination of irons, and although the question as to whether the chemical state of an iron has anything to do with its strength is by no means satisfactorily answered in the affirmative, still it appears to be a general opinion amongst scientific men that it is so, while many practical men maintain that it is the physical or chemical condition of iron which determines the value of it, as regards its strength and durability. Be this as it may, it remains for us to point out some plans recently introduced into practice, which have for their aim the increase of the strength of cast-iron, and of facilities for working it ; as to one at least of which doubt exists as to whether its effects are due to chemical combination, or to changes in the physical condition of the iron so operated upon. The methods of treatment to be noticed now are four in number—(1.) the remelting of iron for a number of times ; (2.) the toughening of cast-iron ; (3.) chilling of cast-iron ; and (4.) the rendering of it to a certain extent

malleable. We shall describe the peculiarities of each of these processes in order, beginning with

(13.) "*The re-melting of cast-iron.*" This is found, generally, to increase its strength; this, however, holding true only of the re-melting up to a certain number of times, for, after which, if the process is repeated, re-melting seems to deteriorate the strength rather than increase it. To William Fairbairn—to whose untiring efforts we cannot refrain from here saying, in the cause of practical science, the world is so much indebted—the knowledge of this fact is due. It is well known that by repeated melting the softer or more graphitic irons, as Nos. 1, 2, and 3, can be so changed as to be converted into No. 4,—that is, from grey with its granular to white with its crystalline structure; "grey" possessing considerable softness and tenacity, with low powers of ultimate cohesion; "white" possessing high powers of cohesion, with brittleness;—a mean therefore between these two conditions of iron will give the highest product of tenacity and cohesion. Karstein's theory of the re-melting process is based upon what has been already stated to be his views as to the combination of iron and carbon (see par. 9); graphite being the result in grey and soft irons. Now, *when iron of this quality is re-melted frequently, the*

free graphite existing in it was forced out, as it were, from the mass in successive portions, being so forced out by the crystallisation of the chemically combined portions,—the amount of graphite forced out being dependent upon the rapidity with which the re-melted iron is cooled. For it is to be observed that slow cooling causes a coarse, granular, soft, and fluid quality in the iron; while rapid cooling causes, on the contrary, a crystallised and hard quality. That this theory of Karstein's is correct, as to the cause of iron being strengthened by re-melting, is corroborated by the experiments of Mr Fairbairn, which showed that the dark-grey graphitic irons are those only improved in strength by the process of re-melting. The iron chosen by Mr Fairbairn to experiment upon was a hot-blast iron (No. 3, Eglinton), but possessing properties which were more the characteristic of No. 1. The strength of this was increased up to the twelfth melting, after which it deteriorated; the result of the eighteenth melting proving that the iron had received all the characteristics of an extract of the class of "white iron."

(14.) We now come to describe the "toughening of cast-iron"—the second of the processes alluded to at the end of paragraph (12.)—which is simply the fusing

or melting of a quantity of wrought-iron along with cast or pig iron in the blast furnace. The grey or graphitic irons are found to combine with the greatest weight of wrought-iron, the "white-irons" combining with very little. In our proposed work on "The Strength of Materials" the reader will find various facts connected with this process, to which therefore he is referred; we meanwhile stating that while the cast-iron is very greatly strengthened by this process, the iron, in the opinion of some, lacks homogeneity,—that is, the combination of the wrought and the cast iron is not perfect. The process owes its discovery to Mr Morris Stirling.

(15.) The process of "chilling" cast-iron, the third of the processes alluded to at the end of paragraph (12.), has for its object the hardening of the surface so as to increase the durability of parts subjected to much friction or rolling. The "chilling" is effected by pouring the melted iron into moulds made of a good conducting material, as cast-iron lined with loam or sand; the depth of the skin of chilled or hardened surface is in proportion to the rapidity with which it is cooled. The process of chilling has been applied by Mr James Howard, of Bedford, of the well-known firm of agricultural engineers, to the hardening of the surface of the *shares of ploughs* with marked effect. In his plan he

uses a stream, or rather streams, of cold water, projected with some degree of force against the surface of the cast-iron body. The process is supposed to have the effect of changing the chemical constitution of the iron, causing the forcing out (see paragraph 13) of the particles of graphite, and giving the preponderance, in the part chilled, to the crystalline rather than the granular portions of the iron. In America "chilling" is largely resorted to in the manufacture of railway carriage wheels—the peripherics of these being chilled—and in the casting of cannon. To Captain Rodman is due the plan, which has been very successful in practice, of large hollow castings, such as cannon, by means of water circulating within the core. This is done by having two water-pipes, one inside the other. Water flows down the inner pipe, which is open at both ends, and rises through the outer pipe, which is closed at the lower end and open at the upper. In chilling iron, Colburn says that it is for the founder to ascertain iron which will chill and those which will not, that it is important that, if the chilled casting be put under great strain, the chill should be blended with the softer iron, instead of there being a distinct line of demarcation between them. This is done by ordering as of the well-known fact that the existence of

or a high column of rising metal over the mould consolidates and strengthens the casting, the same authority recommends the use of steam pressure, say at 100 lbs. the inch, to obtain this head and consolidating effect. The most recent application of the principle of chilling is Major Pallisser's chilled cannon shot.

(16.) The fourth process of treating cast-iron so as to render it malleable and capable of being worked by tools used in the working of wrought-iron, and referred to at the end of paragraph (12), is effected by casting the articles to be so treated in the usual way from pig-iron, and thereafter placing them in a closed retort or vessel in contact with an ore—peroxide of iron, for example—in which there is present a large amount of oxygen. The result is as follows:—The application of heat to the iron—which is purposely moderate in degree to avoid melting or change in the form of the articles subjected to it—to the ore, drives off the oxygen; this combines with the carbon contained in the casting, and partially converts it into malleable iron, imparting to many of the properties of this material. This process is now known as that of the “decarbonisation of Howard.” The process has for a long time been known to French chemists, the celebrated Réaumur shares credit, so early as 1722, his attention directed to

it,—the first English patent, that of Samuel Lucas of Sheffield, dating 1822, and which was substantially that as above described, the castings under his patent process being subjected to the heat of the furnace in conjunction with the ore for so long a period as from five to six days. M. Brüll, the great Continental authority on the subject of decarbonisation of cast-iron, states that the charcoal iron from Ulverstone, in Cumberland, is used by preference for the process, the “grey” quality being best adapted for small, the “white” for large, castings. The iron is, in the first place, put into crucibles capable of casting 66 lbs., or thereabouts, by weight, and subjected to the heat of a steel converter’s fire till melted. It is kept in the fused condition for a period of sixty or seventy minutes, and then cast in the mould made of green or dry sand. The articles thus cast, exceedingly brittle, are placed in iron cylinders or retorts, with dry layers of pulverised red hematite iron ore placed between them, and mixed with some portion of the ore which has been previously used for the same purpose. The cylinders are next subjected to heat in a close furnace, from which air is rigidly excluded, till their contents show a bright red. At this they are kept for four or five days, according as the articles are large or small; the heat is then gradu-

ally reduced till the castings are cooled. The process requires to be gone through, in all its stages, with such care, that it is necessarily an expensive one. If it could be made cheaper, there is no doubt but that the articles heated by it would become more extensively used than they are, comparatively extensive as this is. The cast-iron heated by this process takes a fine polish, not easily affected by exposure to atmospheric changes. It is capable of being worked with the usual cutting tools; it can be rolled, drawn, or hammered, without being heated, and in small pieces welded, although this property in large pieces can scarcely be said to belong to it; it can, however, be easily brazed with copper. It is capable of standing a high degree of heat, and of being case-hardened, and this to a better degree than even wrought-iron.

(17.) As a means of strengthening cast-iron, Mr Zerah Colburn proposes to use a modification of the Bessemer process, hereafter to be described (see paragraph 22), in so far that, in place of subjecting the iron to the blast of air for twenty, he would use it only for the space of three, four, or five minutes. The objection might be made, he says, to this, that if the Bessemer process is to be used at all, why not use it so that the iron might *at once be changed* into steel; but Mr Colburn meets

this by pointing out several reasons why this should not be done. In the first place, a much higher or more superior quality of iron is required to make steel by the Bessemer process, and, generally, a quantity of Spiegeleisen is required to be added to it ; further, the steel is usually run into ingots, and not into the form of goods or castings.

(18.) M. Gaudin obtains an exceedingly hard iron by heating a quality tolerably free from carbon with a small quantity of boron ; and that, by adding the ordinary cast-iron in a state of fusion, a quantity of phosphate of iron, and peroxide of manganese, the same effect is produced. By adding tungstein to cast-iron a still greater degree of hardness is given to it ; so much so, that he says it surpasses everything previously known as a material for tools for cutting rocks, and that crystals of it will cut glass as readily as the diamond.

CHAPTER II.

MALLEABLE OR WROUGHT IRON.

(19.) THE conversion of cast-iron into malleable or wrought iron is effected by getting rid of the carbon, by exposing it in a melted state to the action of the atmosphere in reverberating furnaces, treating it the while to a mechanical process called "puddling;" thereafter, after it becomes agglutinated, taking it out of the furnace and subjecting it to the process called "shingling," and finally working it up with a steam-wrought hammer. The iron thus treated is found to be deprived of its carbon, and is capable of being wrought and hammered; or, in other words, from a brittle, it is changed into a malleable condition. In addition to the capability of being hammered and drawn out without fracture, which iron in this condition possesses, has the even more valuable property, by virtue of which two separate pieces can be joined together by the p

cess of "welding." Familiar as most of us are with the process, it is somewhat singular that we should know comparatively little as to the principles upon which it is based, and that we are therefore at a loss to give some reasonable explanation of it. The process itself is well known, and consists in shaping, in a way dependent upon the form, the ends of the articles to be welded together; then heating them in a smith's fire or furnace to a white, or what is called technically a welding, heat; then taking them out, scattering a few grains of sand on the ends; then striking them on the anvil so as to throw off some of the scales or evaporation; then bringing the ends together in contact; and finally uniting them by two blows from the hammer of the smith, followed by repeated and well directed blows of the hammers of the striker or strikers. The process in practice is more quickly performed than the description of it here given; and, as before stated, its principles, or rather what is welding, are or is not fully known. The best temperature at which the pieces are to be joined has not yet been determined. The sand which is thrown upon the highly-heated surface unites with the oxide formed upon them, and it appears also to aid the close contact of the surfaces. Mr Colburn thus explains the phenomena of welding:—"In all

welding we first employ a degree of heat sufficient to overcome so much of the cohesive force between the atoms of ore iron, so as to allow of sufficient motion among themselves to bring all, or most of the atoms forming the surface, within cohesive range of those forming the opposite surface." A writer on the subject, in the *Mechanics' Magazine*, in commenting upon this explanation, remarks very suggestively, "According to this, heat in welding would appear to have a double function—that of cleaning the surface, and that of rendering the less pressure necessary. But does this explanation meet the normal and chemical influences at work in the operation of welding iron? Why is it so difficult to weld 'burnt' iron? Why is it so difficult to weld steel? Why is pure iron—the iron of the chemist and the laboratory, and not that of commerce—so difficult to weld? These, amongst many other similar questions, are yet very far from solution, and they will probably remain so for many years. It is, however, somewhat strange that more of the obvious qualities of iron are not definitely known." With this suggestive statement we now proceed to : consideration of parts connected with the conversion of cast into wrought iron.

(20.) *The cast-iron to be converted into malleal*

iron is generally subjected to a refining process, by being placed in a furnace so arranged, that while falling in a melted state from the upper to the lower part of the furnace, it is subjected to blasts of air supplied by the blowing engine, and projected through a row of pipes on each side of the furnace. A portion of the iron becomes oxidized, and unites with the siliceous cinder in the fuel, and also with the silica of the sand, adhering to the crude iron. Upon the vitreous slag thus formed the iron floats, and is thus to a large extent decarbonised: The action of the slag is at a certain stage aided by the blast playing upon the surface of the metal floating upon it, by which a portion of the carbon, and almost the whole of the silicum, is removed from it. At this stage the metal is run from the furnace, and broken into pieces small enough to be operated upon in the puddling furnace, to which it is next taken. This is a reverbating furnace, that is so arranged as to cause the flames and heated air to be thrown down upon the metal placed in it—the heat of which air melts the iron, portions of which flow along the bottom of the furnace. To expose each particle as far as possible to the action of the atmospheric air passed in large volumes into the furnace, the iron is puddled,—that is, turned over and

over with an iron tool called a "paddle." The iron becomes agglutinated, and at a certain stage is collected at the ends of the "paddle" tools into balls or lumps, weighing on an average from 60 to 70 lbs. These are removed from the furnace, and, subjected to the action of shingling or squeezing rollers, and of heavy hammers, have their refuse or scoria expunged or squeezed out; after which the iron, thus cleansed—in its new form of malleable iron—is hammered and rolled into the various sections known in commerce as bar, rod iron, and the like. The iron thus obtained is fused with such difficulty that it will, when subjected to high temperature, sooner burn than melt. It is very ductile, and is capable of being welded—one of its most valuable properties. In many works the process of conversion of cast-iron into wrought, above described, is so far modified as that the re-melting in the firing furnace is dispensed with; the cast-iron being run directly from the blast furnace in the reverberatory puddling furnace. In some it is only partially used, and it is only in cases of the best, or of good pig-iron, that it can be entirely dispensed with. Pig-iron produced from very siliceous ores are more difficult to puddle than what is called "*weak pig-iron*", which contains a high percentage of phos-

phorus and sulphur. It is produced from cinders of the firing and puddling furnaces. One of the best forge-irons is Welsh white pig, which breaks with a perfectly solid, white, and crystalline fracture. It is more or less siliceous, and rings like a bell when struck. It is called "strong" pig-iron. The percentage of silicon should not exceed 1 to 1.25 per cent.; this quantity retarding the puddling process, and thus giving time for the impurities to be freed from the iron. A higher percentage was not fixed. It is found to be an advantageous practice to mix the "strong" and the "weak" pig together, in the puddling furnace, in converting them into wrought-iron.

(21.) The puddling process, carried on at such high temperatures, and dealing with such heavy masses of material, is consequently an operation which is certainly one of the most distressing in its effects upon the human frame. Plans, therefore, by which it can be superseded have long been attempted to be realised, with the view, also,—purely commercial in spirit,—of releasing the manufacturers from what has been called the "tyranny" of the "puddlers,"—a class of men who know their value, and often strike, or otherwise discontinue their labours. The difficulty, however, of substituting *machines* for human labour, where intellect

or mind is also exerted, is so great, that it may be doubted whether a "machine-puddler" will be introduced, calculated to give the same results as human-labour puddling. The attention, therefore, of practical men has been directed to the discovery of some process by which puddling can be altogether superseded, and the wrought-iron converted directly from the ore. The best known process for this is that of the celebrated Mr Bessemer, the nature of which will be understood from the details of the process of making steel—introduced by the same inventor—which will, in chapter third, be described. We, meanwhile, note that so much has been done in the direction of converting ore directly into wrought-iron that much of the foreign bar-iron imported into England owes its origin to some process of this nature. The following is a description of a process of direct conversion, which we have compiled from *Transactions of the Iron Manufacture of Great Britain*:—"The direct conversion of ore into wrought-iron dispenses at once with the blast-furnace, and with the refining and puddling processes, and, if properly carried out, should result in the iron being made of superior quality, and at a cheaper rate, from requiring a smaller consumption of ore. The ore to be directly converted is grown

to a coarse powder, and mixed with a quantity of ground carbonaceous matter, and is put into a furnace somewhat like an ordinary reverberatory puddling furnace. A high temperature is maintained, all the mixture of the two powders melts, and, by dexterous manipulation on the part of the puddler or workman, the metallic is separated from the extraneous matter, and treated as in the ordinary process described in paragraph (20). In the process this carbon of the carbonaceous matter is consumed by working with the oxygen of the ore, the metallic matter being left free to agglutinate into a mass, ready for the labour of the puddler. The two objections to the process are, first, the fact that the separation of the metallic matter requires skilled labour, which is, of course, expensive, much of this labour in the ordinary process being effected mechanically by the self-subsidation of the iron on the hearth, it being extracted from the low level; the second objection is, that a considerable waste of metal is the result of a prolonged exposure to the heated gases, and flame while its separation from the extraneous matter is going on. To obviate this last objection, the plan has been adopted of subjecting the mixtures of ore and carbonaceous matter to a preliminary furnace operation,

in which they are kept at a sufficiently low temperature, to prevent oxidisation of the metallic matter, and yet one sufficiently high to consume the carbon of the carbonaceous matter, as before described. From this chamber the metallic matter is withdrawn at intervals, and passed into the reverberatory furnace, balled up and shingled—the process of puddling being dispensed with, as the process is found to agglutinate the metallic matter, without the decarbonising process of puddling being required.

(22.) The process of converting cast into wrought iron introduced some years ago by the now celebrated Mr Henry Bessemer, can scarcely be called a substitute for puddling, being simply a process for forcing oxygen into contact with molten metal placed in a closed vessel, in place of exposing the metal to the oxygen of the reverberatory furnace in the puddling process. The process is so rapid that the conversion of the cast into wrought iron is completed in a few minutes. The iron is kept in a liquid condition during the whole process; the additional heat required to keep it in this state being obtained by the direct combustion of the carbon in presence of the oxygen forced into the closed converting vessel. There is, however, considerable loss of iron resulting from its being “b—”

the process of boiling, all the carbon has to be got rid of, and the result of this is, the evolution of gas in such a way that "the fluid iron boils and bubbles so energetically" that the name given to the process is most appropriate. Certain objections are, however, made to the process, as that the labour required to manipulate the iron is greater than that of the ordinary process of puddling; and further, that there is a more deleterious action exerted by it upon the furnace, and a greater waste of material than occurs either in puddling plate-iron or a mixture of crude iron and plate-metal. At the same time, with regard to this waste, it is right to name the fact, that the waste is less in the boiling process than in the two usual processes,—the refining and the puddling combined. But notwithstanding these defects, the boiling process is so rapidly making way, that, in the words of an authority, "it may fairly be inferred that the time is not far distant when the refining process will be universally abandoned." The most successful mode yet introduced of carrying out the boiling process is, we believe, that patented by Mr James Nasmyth, the celebrated engineer of Patricroft. This has been carried on for several years at the Bolton Iron Works, and *with such results that its use is gradually extending*
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amongst manufacturers. The following is a description of this process :—" It consists in the introduction of a small quantity of low-pressure steam into the molten metal as soon as it is fused. Five-lb. steam is generally used, as at that high temperature the oxygen of steam has a greater affinity for carbon than for the hydrogen with which it is combined, or for the iron; the carbon is rapidly oxidised off. The hydrogen which is liberated has no affinity for the iron, but unites with sulphur, phosphorus, arsenic, and other substances, which are very prejudicial to the quality of the iron. However minute may be the quantity in which they are present, this is always the case, and they are frequently found both in the ores and in the fuel. Besides the chemical part the steam plays with respect to the iron, it has also a mechanical action upon it. It is introduced at the bottom of the furnace, and being thence diffused upwards, it violently agitates the iron, and thereby causes fresh surfaces to become exposed to the oxygen passing through the furnace. In carrying Mr Nasmyth's plan into operation, steam is conveyed from the boiler to a vertical pipe fixed near the furnace door. At the lower end of this pipe is a small tap or syphon to let off the condensed steam, and prevent its being blown into the furnace. To the flange

of the vertical pipe is fastened a cock, with several jointed pieces of pipe, forming in effect jointed bucket-pipes, which allow of free motion in every direction ; the steam tube, or 'rabble,' being bent on the end, so as to inject the steam on the liquid metal. As soon as the iron in the furnace is melted, the puddler introduces this apparatus, which he moves slowly about in the molten iron while the steam pours upon it through the bent end of the tube. In about five or eight minutes the mass begins to thicken, when the puddler withdraws the steam pipe, and the operation is finished in the usual way with the common iron rabble. It is found that, upon an average, from ten to fifteen minutes are saved by this process in every operation or 'heat,' and that during the hottest and most laborious part of the operation. . . . In this arrangement no deleterious substance can enter into combination with the iron, whilst the mixture of fuel and metal, as in the refining process, is liable to deteriorate the metal with sulphur, silicium, etc. In short, the new process has a beneficial effect in purifying the iron, with greater economy than any known process."

(24.) A good deal has been written upon the superiority, or alleged superiority, of forgings obtained by the use of "scrap-iron," and, as some mis-

understanding has arisen upon this point, it will be well briefly to allude to it. The notion that scrap-iron is so very valuable for forgings arises from the fact that, by repeated workings, iron is very much improved in quality. This is doubtless the case, but only within certain limits, for, as in the case of remelted cast-iron, while the strength is increased up to a certain number of meltings, beyond that number the strength deteriorates; so in the case of repeated forgings and workings of wrought-iron,—up to a certain point these are advantageous, but beyond that “the strength decreases in the same ratio that it rose.” Moreover, the quality of the scrap-iron must exercise a great influence upon that of the forging produced from it. This is so obvious, that it is strange it has been overlooked; and yet it is so in many cases, else how is the idea so pretty generally held, that the mere “accumulating shreds of iron, and fagotting them indiscriminately, would produce a superfine piece of material at the completion of the job?” The very uncertainty as to the value or quality of the piece making up a heap of scrap-iron must militate very much against the chances of obtaining metal from them homogeneous in character; and if a poor quality of iron is present, this must exercise a bad influence

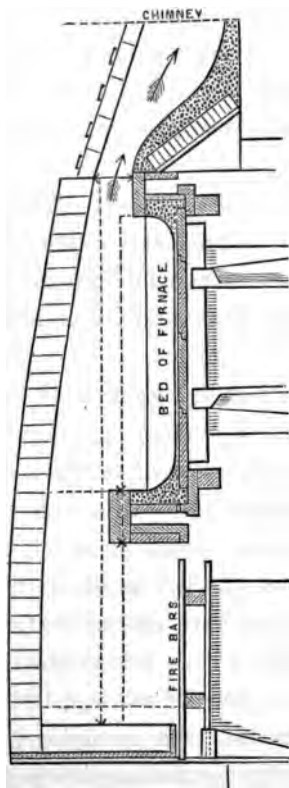
upon that of the forging. Another point is, that as each quality of iron has a different welding point, it is obvious that, in large forgings, requiring a large bulk of scrap-iron, the uniformity of the metal will be impaired. This is well known in practice ; for, in turning up or otherwise working forgings of scrap-iron, portions of different degrees of hardness are met with in the same article.

(25.) In the article in the *Engineer* already quoted from, descriptive of the machinery of the iron manufacture, there is an illustration and description of a puddling furnace, and of the process carried on in it, which we here give :—

“ Fig. 4 shows a section of a puddling furnace—to a scale of one quarter of an inch to a foot. The hearth, which is composed of fire-brick set on edge, or a cast-iron plate covered with a layer of slag, is almost level, but, nevertheless, at the lowest point of which is the floss-hole, for the removal of slags which during the process of decarbonisation have accumulated in the furnace. The hearth generally is 6 ft. in length. It is separated from the fire-place by a bridge 12 in. high, and one brick in thickness. For rendering the removing of the clinker easier, the fire-bars are made *moveable*, which cover a space having for its length

the width of the hearth next the bridge, while the other way it measures, according to the size of the

Fig. 4.




furnace, from 2 ft. 8 in. to 3 ft. 4 in. To cause the draught through the apparatus, a chimney is constructed of bricks, and strengthened by numerous iron ties, and is from 30 ft. to 50 ft. high. The upper part of this shaft is provided with a sheet-iron damper, which is opened by a chain and lever, by which the amount of air passing through the furnace can be regulated by the workman. The walls of this arrangement are all composed of ordinary masonry, but the dome and all parts which are exposed to a high temperature are made exclu-

sively of good fire-bricks, bedded in clay. The

exterior of this mass is coated with a strong casing of cast-iron, firmly held together by clamps and wedges; and by this means not only the perfect solidity of it is made secure, but also the entrance of cold air, which otherwise would penetrate through the crevices in the brickwork, is stopped. The door communicates with the grate, and is closed either by an accumulation of coal used as fuel, or by sliding doors raised by a chain and lever. In this country the feeding hole of the furnace is generally closed. The opening communicates with the hearth or sole of the furnace. This door is principally used during the process of puddling for working the metal with an iron rod, and is closed by means of an iron frame filled with fire-bricks, and raised by a chain and lever. There is another aperture, sometimes on the same side of the furnace, but a great deal nearer to the chimney, for charging the refined metal, and cleaning out the apparatus as soon as each operation is ended, and this is therefore kept close, while working the charge, by an iron plate. The hearth, as above stated, is frequently composed of a cast-iron plate, covered with a fusible slag, and in this case a space is left for the circulation of cold air between it and the brickwork; the temperature to which it is


constantly exposed is by this means kept lower than the point of its fusion, and, consequently, the plate remains uninjured, when otherwise it would become rapidly destroyed. The puddling of fine metal in this furnace is conducted as follows:—The iron is conducted to the furnace by a shovel, and is piled up round the sides of the hearth till it almost touches the dome, but taking care to keep the centre of the sole clear for working the charge, as well as to allow the heated air to freely circulate round the broken fragments. A portion of rich slag and iron scales is added afterwards to the broken metal. The doors are then closed, fresh fuel put on the grate, and the damper at the top of the chimney closed. In about half-an-hour's time the sharp edges of the fine metal begin to melt, and flow on the bottom of the hearth. At this stage the workman removes a small iron plate, by which, during the first operation, a small opening in the working door is closed, and with an iron rod stirs the melted portions of metal, so that new surfaces may be exposed to the oxidising gases passing through the furnace; and to prevent it running together in one mass, he removes it to a certain distance from the bridge. When the whole charge has been thus *brought to a pasty state*, the fire is lowered, the

damper closed gradually, and a little water may, if necessary, be thrown into the furnace. From the evolution of carbonic oxide gas, the metallic bath now appears to boil; this gas, on reaching the furnace, immediately takes fire, and burns with a blue flame. The metal has now to be kept constantly stirred by the puddler with an iron tool called a paddle, and thus fresh surfaces are continually exposed to the action of the gases in the furnace. It is desirable, however, that the metal should not be exposed to the direct action of the atmospheric air, as it would become rapidly oxidised, and for this reason the working door is not opened, unless it is quite necessary to the carrying on of the work. After a while the metal begins to lose its coherence and gets sandy, or what the workman would call dry. The evolution of oxide of carbon now rapidly declines, and soon ceases altogether; but the mass is kept continually stirred till it has obtained a uniform granular appearance. When this state is arrived at, the fire is again forced, and the damper gradually raised; the sandy particles now agglutinate, and offer considerable resistance to the paddle. The iron now is said to work heavily, and for this purpose the floss-hole at the end of the furnace farthest from *the bridge* is opened, and a portion of the scoria run



off. All that remains is for the workman to form the iron into balls, which he does by attaching a small portion to the end of the paddle, and so rolling it in the hearth as to collect other fragments, which become firmly welded to it. The charge is in this way collected into lumps, weighing from 60 lb. to 70 lb. each, which are placed in the hottest part of the furnace by a kind of rake called a dolly, which is heated to redness before being used, and in this place they are pressed, in order to squeeze out the slag contained in the spongy mass. The time occupied in this making of the balls is about twenty minutes, when the doors are closed for a little, and the dampers opened so that the particles of the metal may be welded closely together. The loupes are then removed successively from the furnace, and placed either under the hammer or squeezer, in which case they are often welded to a long iron rod, which serves the purpose of a handle to the workman. On the contrary, where they are passed directly to the roughing rollers, as in most parts of Wales, they are lifted directly from the earth by the help of heavy tongs only.

The charge of a puddling furnace is usually from 1 cwt. to 6 cwt. of fine metal. When very pure cast iron is to be treated, such as that prepared from



charcoal, the preliminary operation of refining is sometimes dispensed with, but its previous purification is almost indispensable for ordinary rough metal. In the course of twenty-four hours each furnace receives from ten to eleven charges, and the average loss experienced by the fine metal is about 9 per cent. on the quantity treated. For each finery, about five puddling furnaces are required, and every charge of puddled metal requires the combustion of just its own weight of coals. The operation may be divided into four distinct periods. The melting of the refined metal begins at the expiration of twenty or twenty-five minutes. When an hour-and-a-half has expired the charge is completely reduced to a sandy state. While in this state, it is kept heated for another half-hour, and thus the boiling is begun; and this occupies the same length of time."

CHAPTER III.

STEEL.

(26.) STEEL occupies a position between wrought and cast iron, containing what may be called an intermediate quality of carbon. It is capable of having great hardness given to it by the process of what is called "tempering," that is, heating it and then plunging it into cold water. The usual mode of making steel is by introducing bars of wrought-iron along with carbon into retorts, and maintaining them in a furnace at a red heat for a considerable time. This process is known as that of "cementation." It is also made by the direct process, invented by Mr Bessemer, of which we shall hereafter give details, noticing meanwhile more fully the process of cementation above alluded to. The iron bars, which are of the best quality, the charcoal-iron of Sweden and of Russia being held in the highest estimation, are placed in retorts, *which are set in a furnace somewhat like that used in*

gas-works. The retorts are made of fire-tiles, and are so placed in the furnace that the flames and heated gases can play round the whole or the greater part of their surfaces. The bars of iron are packed closely, and enveloped thoroughly in a carbonaceous cement, in such a manner as to prevent them coming in contact with each other. When the retort is filled, the whole are covered with a layer of the cement, over which is placed a layer of damp siliceous sand, and the whole tightly covered by fire-tiles and fire-clay. The carbonaceous cement used to envelope each individual bar is composed of hard charcoal finely powdered, one-tenth of its weight of ashes, together with a little common salt. The bars have their ends projecting slightly from the retort end, so that each may be partially taken out from it and examined, to note the different stages of the process. The retort thus filled is gradually heated by a slow fire till the temperature reaches the point of 100° of Wedgwood's pyrometer; to alter which temperature it takes about twenty-four hours. This temperature is then kept up for a period of about eight or ten days, according to the degree of carbonisation required to be given to the metal. The fire is then withdrawn, and the retorts, with their contained bars, *allowed to cool gradually down.* When properly cooled

down, the bars are taken out, and form what is called "blistered steel," so named from the numerous blisters with which the surface is covered, arising from the gases evolved in the process of the cementation passing out from the metal. The change effected by the process in the nature of the metal is very marked; no longer of a fibrous, it is altogether of a crystalline nature, and if required to be used for certain purposes, it has to be drawn out or reduced within rollers or hammers, in order to bring back to it some of its former qualities. In its form of blistered steel, however, it is used largely for many purposes, as, for example, facing of hammers, welding to iron for tools, and spades, and shovels, and the like. When blistered steel has to be drawn out or reduced by the rolls, it forms "spring steel." When made uniform in its texture by repeated welding and rolling, or reducing, it forms "shear steel," which is largely used for the making of tools and the various kinds of cutlery. What is called "cast-steel" is produced by breaking blistered steel into small pieces, and placing them in crucibles or pots, each of which is capable of containing from 30 to 40 lbs.; two of these are placed in a furnace, in which, by the aid of a strong draught of air, a white heat is maintained for three or four hours. When

melted, the crucibles are taken out, and their contents poured into iron moulds, and left there till they are sufficiently cooled to be taken out. The metal thus obtained is perfectly homogeneous, or of uniform texture; but it is exceedingly brittle and hard. To rid it of these properties, it is usually subjected to repeated hammerings and rollings at a low heat, till it becomes malleable; in which form it is used for a great variety of purposes—making of tools and cutlery. It possesses great strength, and by its judicious tempering it can have imparted to it any degree of hardness and elasticity. The improvements made during the last few years in the manufacture and in the adaptation of it to various purposes in the constructive arts, have been very striking, and have, in truth, completely revolutionised the trade. There is, practically, no limit to the size of the ingots or blocks of steel so cast, as has been proved by the monster blocks, weighing 40,000 lbs., exhibited in the 1862 Great Exhibition of London, by Krupp, a German manufacturer. This same gentleman has also succeeded in fashioning these blocks, by various mechanical processes of hammering, rolling, etc., into various objects, such as axles, cannon, and wheel-tyres, in one piece, or continuous ring, without a weld. To Herr Mayer—another German worker—

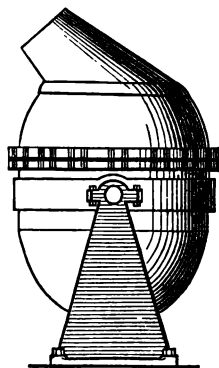
of the Bocham Steel Manufactory, is due the invention or discovery by which cast-steel can be used, like cast-iron, to form various articles. Simple and natural as this way of using cast-steel appears to be, it is however the fact, that so many difficulties presented themselves in the way of its realisation, that at one time they appeared to be insuperable, till Herr Mayer—German gentleman just named—discovered the process which has been used with remarkable success. Were we to give the details of that process are we cannot make known to the reader, as they are a secret of the establishment.

(27.) We now come to describe the Bessemer process of making steel from cast-iron. When first introduced this had for its object the conversion of wrought-iron into steel by simply oxidising a sufficient amount of carbon from the cast-iron, so as to convert it into steel. But steel of a uniform quality was not easily obtained by this process, from the difficulty that was experienced in practice of stopping the decarbonisation at the exact time required. The plan was therefore adopted to extract the whole of the carbon from the iron in the first place, thus converting the cast-iron into malleable iron, and, in the second place, introducing a measured quantity of cast-iron to the mass, thus giving it sufficient carbon to form it into steel. Fig. 5 illustrates

converting vessel used in the manufacture of Bessemer
 steel. It is made of the best boiler plate, and lined
 with powdered "ganister," which is a siliceous sand-
 stone met with in the neighbourhood of the coal for-
 mations. This ganister is found

to be the material best calculated
 to stand the intense heat created
 during the process of conversion.
 The vessel is mounted, as shown
 in the drawing, fig. 5, in bearings,
 and is swung on centre pivots,
 which admits of the vessel being
 tilted forward, so as to empty
 its contents into the vessel put to
 receive them. One of the bear-

Fig. 5.



ings, or standards, is made tubular, and through it the
 blast of air is conveyed into the interior of the vessel.
 The following is the description of the process, from

the pen of a practical writer :—"The species of iron
 used by Mr Bessemer is No. 1 pig-iron, hot-blast,
 melted at the Cleaton Works, from red hematite. This
 is melted in an ordinary reverberatory furnace, and is
 poured into the converting vessel by the mouth, the vessel
 being on its side, so as to keep the tuyeres clear of the
 melted metal; the blast is then turned on, when the

vessel is turned upright. The force of the blast rushing through the tuyeres now violently agitates the whole mass of metal. The silicium present in the cast-iron first combines with the oxygen of the air to form silicic acid, which, in turn, combining with a portion of oxidised iron, floats on the top of the metal as a slag. The heat, by the combustion of the silica and a portion of the carbon, gradually rises, and in about ten or twelve minutes from the beginning of the process, the carbon in the iron begins to be oxidised with great rapidity, producing a most intense combustion. In a short time the metal becomes pasty, and by the intense heat and action of the blast, is swelled up in a frothy state to nearly double its original volume, thus presenting a large surface to the action of the blast. At this stage the carbon is burnt off with great rapidity, producing a series of explosions, and projecting the liquid slags out at the mouth of the vessel, which, in addition, pours forth a voluminous flame of burning carbonic oxide and other gaseous products. When this flame has just subsided, the metal has nearly approached the state of malleable iron; the vessel is therefore turned on its side, the blast turned off, and the measured quantity of charcoal pig-iron, containing a *known* amount of carbon, is introduced into the

vessel. The blast is then turned on, and the temperature is quickly raised for a few seconds, when the process is complete. Thus, in from twenty to thirty minutes, from 1 to 10 tons of cast-iron can be converted by this process. From the converting vessel the steel is run into a large ladle, by inverting the vessel, which is conveyed away, and is poured into the ingot-moulds. The converting vessel, when first started, is heated gradually with a coke fire, when the blast is gradually turned on, and the heat increased; the vessel, after being heated to the proper temperature, is inverted, when the burnt coke falls out. The tuyeres, of which there are seven, are composed of fire-clay, each having seven holes, and are inserted in the bottom of the converting vessel."

The difficulties which Mr Bessemer met with in carrying out his process were great, and those he most graphically describes in a paper read before the British Mechanical Section of the British Association, held at Birmingham in 1865, and which will be found *in extenso* in the volume for 1865 of "Engineering Facts and Figures" (A. Fullarton & Co.). Many of these difficulties were mechanical, but others, and these were the most important, had regard to the quantities or quality of the iron best adapted to the process, for, after a certain degree of success had been obtained in

the production of steel of good quality, it was suddenly discovered that the steel was no longer good. It was only after the expenditure of much time and money that the reason was discovered, and that only certain qualities of iron were adapted to the process, and that none which contained more than "about one-tenth of one per cent. of either sulphur or phosphorus would make good Bessemer steel." The reason of the success of the first trial was, that good Blaenavon iron had been used, and this by the merest chance; so that when inferior irons were used, a bad quality of steel was the result. Another great help towards the perfecting of the process was the use of manganese. The use of this was indicated so long ago as 1839 in the patent of Mr J. M. Heath, who, having resided long in India, had observed that the celebrated Wootz steel owed much of its value to the presence of manganese. Mr Heath patented the use of the metallic manganese or carburet of manganese. This had the effect of rendering inferior coke-irons useful in the making of cast-steel; it also removed from them their "red-shortness," and made the steel procured from them more easily worked. The result of the introduction of this material gave an immense impulse to the trade of Sheffield, where it was *first used*. Manganese has been used for many years

in every cast-steel work in Europe ; and Mr Bessemer has found its use to be of immense advantage in his process. In the course of the costly experiments made by this gentleman, it was found that if the air was continued to be blown in amongst the iron until it was completely decarbonised, the iron produced was "burnt ;" on the other hand, if the blowing was stopped at a stage before complete decarbonisation, the metal resulting was in no way to be depended upon, as the conversion might be stopped before being completed, and at a point dependent upon mere chance. But when the metal is present in the mass, while under the operation of the blowing, the affinity of which for oxygen is greater than the affinity of iron for oxygen, this burning of the metal is prevented. Manganese is a substance which so acts, and as this is present in the "Spiegeleisen," or "spathose" iron of Rhenish Prussia, Spiegeleisen is used by Mr Bessemer with every success. A patent for the use of Spiegeleisen in the conversion of iron into steel was taken out by Mr Mushet, but it was not considered valid by many authorities, as the material had been used for years previous to the date of his patent, which indeed was allowed to lapse by the third year's stamp-duty being neglected to be paid. Mr Mushet, who certainly has made the subject of iron and

steel manufacture his special study, thus describes the effect of adding Spiegeleisen to Bessemer metal :—“(1.) The metallic manganese, by its superior affinity for oxygen, de-oxygenates the decarbonised metal, and renders it sound and free from red-shortness. (2.) The carbon of the Spiegeleisen steelifies the mixture, and improves it when stiff or hard metal is required. (3.) The iron of the Spiegeleisen adds to the weight of the charge, and may therefore be considered as a gain to nearly the amount of its weight. (4.) The silica which is found in Spiegeleisen has the effect of reducing the boiling or agitation of the pneumatised metal, when poured into moulds, and is therefore beneficial; and it is not present to any injurious extent in Spiegeleisen. (5.) The hardness, or temper of the Bessemer steel, may be increased at pleasure by increasing the dose of Spiegeleisen. (6.) When Spiegeleisen is added to Bessemer metal containing sulphur, and the pneumatic blast is turned on so as to eliminate the carbon and manganese of the Spiegeleisen, a portion of the sulphur of the pneumatised iron is carried off by the manganese, and thus, by repeated additions of Spiegeleisen, and subsequent elimination of its manganese, pneumatised cast-iron may be wholly desulphurised. (7.) In a similar manner, Bessemer metal containing phosphorus may be

dephosphorised by employing titanic pig-iron, in repeated doses, to eliminate the phosphorus; and when both sulphur and phosphorus are present, both may be eliminated by repeated additions of Spiegeleisen and titanic pig-iron, the pneumatic blast being turned on after each addition made to the pneumatised cast-iron."

(28.) The irons used by Mr Bessemer in making steel, up to the present time, are the hematite irons—those containing large quantities of sulphur and phosphorus not being adapted to this process. But Mr Bessemer states that, if manufacturers of pig-iron will make use of lime that contains no fossil remains, a less amount of phosphorus will be contained in the iron, and if they will also take the trouble to wash their coals, which they can do at an expense of 2s. per ton, they can produce iron commercially worth 20s. a ton more than they now make. By using great care in the production of pig-iron, a much larger quantity of iron will be available for converting into steel by his process. The following is Mr Bessemer's latest exposition of his process, as explained at a meeting of the British Association at Nottingham, in 1866:—"In the manufacture of steel, as now carried on, blasts of air are driven vertically upwards through the molten metal. In doing so, we act first upon the

silica present by means of the oxygen. As soon as this substance is thoroughly oxidised, the oxygen acts upon the material the next most greedy of oxygen, viz., carbon. As soon as this takes place, a most violent ebullition ensues, and the flame and conversive heat being generated, the temperature of the metal rises enormously as the process goes on, so that we not only get it wholly decarbonised, but we get it into such a state of fluidity that its temperature is not only sufficient to keep it in that state, but if other ingots are put in, the heat is sufficient to reduce them also to the same condition. As soon as the metal has been wholly decarbonised, we introduce the Spiegeleisen either into the vessel itself, or into the ladle in which the metal is poured to be cast. The effect is, that the tendency to red-shortness which creates a difficulty in forging, is at once removed, and the metal which had been previously rendered malleable by the pneumatic process becomes less red-short." We have already alluded to the difficulties in the way for mechanically conducting the process. Those by the apparatus of the form illustrated in fig. 5, have been so removed that, from a capability to operate upon so small a weight of metal as 40 lbs.—the limit of the process in its first stages—the weight of 25 tons are operated

upon now at one operation. Such, indeed, has been the remarkable revolution created in the steel trade by this process, that from a production of 1000 tons of steel per week, the produce of the manufacture of four or five years ago, it has now risen to a produce of 3000 tons; and a great number of establishments, both in this country and abroad, are now constantly using the Bessemer process. Before its introduction, the market price of the cheapest kind of steel was £36 to £40 per ton; that of the better kinds from £50 up to £80 per ton; but since it has been so successfully worked, thousands of tons of cast-steel of excellent quality are in the market at £13 to £14 per ton. Its use is being largely extended, more especially in the construction of various parts of locomotives and of rails; and in many other departments of construction it is daily becoming more and more used. In fact, for every purpose almost in which malleable iron has been and is used, the Bessemer steel is available,—the only drawback being at present its high price as compared with malleable iron—being nearly double the price; but even this difficulty will, in process of time, be obviated, as the superior economy, both on account of the lightness and the strength of articles made of it, becomes to be appre-

ciated, independently of the fact that the manufacture will in itself be more and more economically carried out, as improvements in the process are made, and the range of its applicability widened.

(29.) Desirous to make our record of the present condition or state of metal manufactures used in the constructive arts as full and complete as possible, we devote a paragraph to the description of processes of making steel, other than those already noticed. (a.) In one process a cast-steel very useful for some purposes is produced by fusing wrought-iron with carbon in a crucible, the hardness being regulated by the quantity of charcoal used ; for soft-steel, less than 1 per cent. being required ; for tool-steel, from 1·5 to 1·7 per cent. The soft-steel produced is capable of receiving a high polish, and of being case-hardened without bending. What is called in the trade "hemogeneous iron," is a species of "mild-steel," and has been introduced by a Sheffield firm. It possesses a tensile strength double that of good malleable iron. On the Continent the German process of refining is used, and a steel being produced from crude iron by the decarburising effect of a blast in a refinery furnace. Charcoal is used to melt the pig-iron, and a strong *blast is projected* over the surface of the molten lead ;

the mass being stirred up so as to bring the whole under the prismatic process. (b.) Another process is used for the production of a steel of a very superior kind, at the works of M. Bagenly, near Paris. The ore is placed in a furnace of a peculiar construction, with which other furnaces are connected, care being taken that the gaseous products of those should alone come in contact with the ore in the larger furnaces. The ore, subjected to these for five days, is changed into what is called by the manufacturer "spurge." When the process is completed, a ton of this spurge is removed, and saturated with oil or grease, in order to supply the mass with carbon. It is next placed in retorts of wrought-iron, and subjected for two hours to a heat necessary to drive off any excess of carbon. The spurge thus treated is next reduced to a powder, and then compressed by powerful machinery into bars. These are removed to a crucible, one ton being mixed with five tons of coke; from the crucible it is run—after being melted—into ingots, and finished by hammers in the usual way. (c.) The process of producing steel directly from cast-iron in the puddling furnace has long been known, but it is only recently that puddled steel has been largely introduced into the market. The process is the same as that described for

converting cast into malleable iron (see paragraph 16), with this difference, that the puddling process is stopped at a point before the whole of the carbon is exhausted; the amount or percentage of carbon which the steel is allowed to retain being from one-half per cent. to one per cent. When this stage of decarburisation of the cast-iron is reached, the puddler closes the damper reducing the heat, and collects the steel into balls, all which are hammered and rolled in the usual way. The objection to puddled steel, however, is, that it is not homogeneous or uniform in quality; but this may be got rid of by selecting the best bars produced, as first described—piling, heating, and rolling them into plates or bars. Treated this way, a tough, malleable steel is produced, which in many processes has superseded the use of wrought-iron. (*d.*) What is called the “Uchateus” process of making steel—from the name of the inventor, Captain Uchateus—consists in melting the pig-iron in a cupula, running it into cold water, in which a dash-wheel revolves, and the action of which reduces it to a granulated state. These grains of iron are next mixed with the powder of oxide of iron, or with sparry-iron, spathose-ore, and fine clay, to the extent of from 20 to 30 per cent. The materials thus *mixed* are placed in a crucible, and melted in a

furnace. The cast-iron granules part with some of their carbon by the action of the oxide, and a slag is formed which purifies the steel. If the granules of cast-iron are large, the steel produced is hard ; if small, it has the opposite property. (e.) M. A. Berard produces a quality of steel, which is said to be very superior, by operating on the crude, melted metal alternately, with reducing and oxidising agents. Gases are used to produce the necessary heat—a reverberatory furnace being employed. Atmospheric air is sent through the metal, for the space of fifteen minutes, on one side ; the other side being heated with a mixture of hydrogen and carbonic oxide gases fused from sulphur. This mode of treatment is then reversed. In this process part of the iron is oxidised to a protoxide, the earthy metals, as calcium, silicium, and aluminum, etc., being also oxidised ; these probably combining with the oxide of iron, and forming compound silicates, the sulphur, phosphorus, and arsenic pass away on being oxidised. The oxide of iron is reduced, and the other metals form scoria, which, as usual, floats on the surface ; a volatile hydrogen compound being formed by any sulphur, arsenic, or phosphorus which may have escaped being oxidised. The air-blast is brought finally into play, in order to decarburate the metal, and it is thus converted into steel.


CHAPTER IV.

COPPER—LEAD—ZINC—TIN—GALVANISED IRON— BRASS—ALLOYS.

(30.) COPPER is obtained from the ores to which the name of sulphuret of copper is given. The following shows the constituents of a sulphuret of copper which contains 10 per cent. of copper:—"Copper," 10; "sulphur," 15 to 20; "siliceous matter," 45 to 55; "iron," 20 to 25. The first process in extracting the copper from the ore is to calcine it, which is done in the simplest way, by roasting it in the open air with a pile of burning fuel, coal, or brushwood. When a furnace is employed, it acts somewhat in the same way as a reverberatory furnace employed for like purposes. Doors are provided at the sides to facilitate the spreading of the ore over the hearth, and vaults, technically known as "cubs," are provided under the hearth into which the calcined ore drops as it is calcined by the heat of the furnace. A calcining

furnace is generally made with two tiers ; the flames and heated gases form the lower, acting upon the materials placed in the upper tier. A usual weight of charge of ore to a furnace is four tiers ; this being placed, in the first instance, on the upper tier, allowed to lie there for some hours, during which it is well stirred with rakes, and then passed to the lower tier. In this the heat is much greater than in the upper tier, and the ore is subjected to it for six hours, being stirred every two hours. From the vaults underneath the furnace, the calcined ore is removed to a second furnace, technically known as the "ore furnace." It is a reverberatory furnace, consisting of three parts—the grate, the hearth, and the flue. The hearth or furnace is elliptical in shape, and lined with fire-brick of the most refractory character, in order to resist the intense heat projected into and passing along it from the grate. The calcined ore is placed on the "bottom" of the hearth, the preparation of the "bottom" constituting one of the peculiarities of the copper-smelting process. A layer of fine sand is first laid on the earth, and calcined by the heat of the grate ; after this the whole is levelled and consolidated by being well rammed. The bottom thus formed is not exactly level, but is made with a slight incline towards

the "top hole" of the hearth, to facilitate the withdrawal of the melted ore. After the bottom is thus prepared, it is again subjected to the action of the heat of the grate for a period of twelve hours. A second layer of sand, some four or five inches in depth, is next put in and heated, rammed, and consolidated as before. When this is done, the bottom is subjected to a high temperature, when, after an interval, some metal is thrown in upon the bottom and the heat again applied, and afterwards the heat is lowered to a dull red heat. The furnace is now ready for a full charge of calcined ore: this is melted, and after its withdrawal the furnace is cooled down to a red, dull heat, when a second full charge is put in, withdrawn, and the heat again reduced. This is done till three full charges are melted in succession, after which the furnace is kept in constant work,—a good "bottom" lasting for nearly twelve months. In some cases the bottom fails, and has therefore to be removed at the expenditure of much time and cost. The "charge" to the furnace weighs from 3 to $3\frac{1}{2}$ tons, and is made up of certain materials of which the proportions vary according to the nature of the manufacture. A charge which is considered a good one is made up as follows:—*Calcined ore, 30 cwts.; raw ore, 26 cwts.; sharp slag, 8 cwts.;*



this only makes a weight of a little over two tons. The object of the action of "ore furnace," now described, is more to act upon the slag than upon the copper itself, inasmuch as the slag may carry off a large proportion of the copper. To get rid of the siliceous slag, with as small a proportion of the ore in it as possible, is the object of the copper smelter. When the contents of the furnace are fairly melted, the whole are well stirred, then allowed to settle, so as to bring the slag to the top; this is carefully taken off, and the metal run into pigs, in the state known technically as "coarse metal," or, more generally, "regulus." The stamping and crushing, or pulverising, of this regulus, and the subjecting of the pulverised material to the action of a strong heat, in a furnace somewhat similar to the "ore furnace" just described, constitutes the "third" process. When the calcined or melted regulus is passed from the furnace, it is again passed into a third furnace and melted, thus passing through the fourth process. The fifth process is roasting the produce of the fourth process in a furnace, which is provided with a side door through which the material is passed. The charge is kept in this furnace for about twenty-four hours, and tapped and run into moulds or pigs. Where the works are conducted

well, a sixth process is another roasting to which the metal is subjected. The last and most important of all the processes is that of "refining." The refining furnace is the same as the ore furnace, only smaller: it is charged at the side, and the metal is withdrawn from a door at the front. The copper—in its form known technically as "pimple" copper—is put into the furnace in masses of some five or six tons, and is subjected to a fierce heat for several hours, and is skimmed to take off the slight slag. Air is at this stage let in by the side door till the metal begins to "work" or coil up, when it is slightly stirred or moved on the surface with a "rubble" or rake: this is continued for about two hours, till the copper begins to "blister," or to have its surface marked with rising black scales. In this condition it is known as "blistered copper." The side door being kept open, the copper solidifies during a period, more or less lengthened according to circumstances, from two up to six or seven hours. The doors are then closed, sealed, or luted tight, and the metal is re-melted and allowed to remain in the furnace for three or four hours. A small portion is then taken out by the "head refiner," worked into an ingot, and tried on the anvil. If found good, a quantity of lead, *in the proportion* of 16 lbs. to the ton of copper, is

passed into, and stirred well up with, the melted copper in the furnace. The copper is tested, as above described, from time to time, and, according to its pitch or grain, the refiner manipulates the copper with the stirring pole, gives more air to the furnace, and retards or hastens the process according to circumstances. The copper, when at the proper state of refining, is cast into "ingots," "tiles," or "wire bars," according to the demands of the trade. If what is called the "best select" copper is required, the refining process is gone through a second time. The following is an analysis of "select copper:—"Copper, 99·80 to 99·85; iron, 0·10 to 0·15; lead and antimony, none; the oxygen and silver are of no consequence. If select copper contains 0·01, or even a trace of antimony, or a proportion of iron equal to 0·10 and copper 99·85, it will not sell. The following is an analysis of the very best cake copper:—"Copper," 99·60 to 99·70; "iron," 0·10 to 0·15; "lead," 0·10 to 0·15; "antimony," 0·40 to 0·60; silver is objectionable.

(31.) LEAD.—The most important of the ores of lead is what is known as "galena," which is a sulphide of lead. It is found in beds and in veins in the granite, gneiss, sandstone, limestone, and clay-slates.

formations. In this country the richest deposits are in the mountain limestones of the north of England, and in the counties of Derbyshire and Cumberland. Galena is frequently found associated with iron and copper pyrites, blench, the carbonate of lead, and with other ores of lead; but it usually occurs in a gangue of sulphate of baryta, calc-spar, spathose iron, or quartz. Galena is lighter in colour than ordinary lead, has a metallic or strong appearance, is very brittle, and, when broken into powder, has a brilliant, blackish grey look. Its specific gravity varies from 7.5 to 7.8, and when pure it is composed of 86.55 per cent. of lead and 13.45 of sulphur. It is, however, rarely met with in its pure state, being almost always mixed with a certain amount of earthy impurities and silver. The ore of lead next in importance to the "sulphide" (in galena), is the "carbonate." This is very brittle, is white or greyish white in colour, and of a specific gravity of from 6.46 to 6.50; and its average composition is 83.56 per cent. of lead in the form of an oxide, and 16.05 of carbonic acid. The reduction of galena—stated above to be the most common of all the ores of lead—in the English process, is by what is called "double decomposition," and the first process of which is the

demonstration of metallic or ordinary lead, by reducing the galena by the aid of heat and the action of the atmosphere to a mixture of sulphide, oxide, and sulphate; and the second, the reduction of the resulting oxy-sulphide by adding carbonaceous matter. These processes are carried out by the aid either of the reverberatory furnace, the slag hearth, or the cauldron furnaces. The lead obtained by the above processes generally contains a certain proportion of silver as well as of earthy impurities; and to obtain the silver these impurities have to be got rid of by the aid of what is called "calcining," which consists in subjecting the lead to the action of a reverberatory furnace, and is the influence of the gasses which pass through it; after which the process of refining is gone through.

(32.) ZINC.—This metal is bluish-white in colour; when broken presents a crystalline fracture very brilliant, but which soon tarnishes in a damp atmosphere. At ordinary temperatures it is brittle, but when heated to temperature between 212° and 300° Fahr. is capable of being hammered and drawn; when the temperature reaches 450° it is again made brittle; the melting point is 773° Fahr. The metal is found usually in combination, either with sulphur, oxygen, carbonic acid, sulphuric acid, or with silver. The ores are the

"red oxide," the "sulphuret," the "carbonate," and the "silicate." The "red oxide" is found in abundance at New Jersey in the United States; the "sulphuret," commonly known as Blind or Black Jack in Cornwall in England; the "carbonate," or "calamine," in Cumberland and Derbyshire; and the "silicate," at the Mendip Hill, Dumfriesshire, and in Derbyshire. The greatest part of the zinc of commerce is made in Belgium and Germany,—the works of the Veille Montague Company being the most extensive property in the world.


(33.) TIN.—The principal ore of this metal is the oxide. Pure tin ranks next to silver in the whiteness and purity of its appearance. It is malleable and ductile. The melting heat is 442° Fahr., and this temperature should be as little exceeded as possible where it is desired to retain the fine and pure white colour for which the ore is distinguished. The ore—the oxide of tin—is reduced in a reverberatory furnace, being mixed with coal, carbon, or powdered anthracite, in the proportion of one-fifth of the carbonaceous matter to four-fifths of the ore. Previous to passing the ore, the carbon, or the powdered anthracite, into the reverberatory furnace, they are well mixed together. When *fused*, the whole is well rubbed or mixed with a rake,

and, after a certain period has elapsed, the metal is drawn off into vessels, and from thence, after the solidified slag is removed, passed into moulds. In this condition it is mixed with several impurities, which are finally got rid of by the process of refining.

(34.) GALVANISED IRON.—The following is a description of one of the methods employed in this country :—
“The sheets to be galvanised are pickled, scoured, and cleaned, just as for ordinary tinning. A large wooden bath is then half-filled with a dilute solution of muriate of tin, prepared by dissolving metallic tin in concentrated muriatic acid, which takes two or three days, and two quarts of the saturated solution are added to 300 or 400 gallons of the water contained in the bath. Over the bottom of the bath is spread a thin layer of finely-granulated zinc, then a cleaned iron plate, and so on—a layer of finely-granulated zinc and a cleaned iron plate alternately—until the bath is full; the zinc and iron, together with the fluid, constitute a weak galvanic battery, and the tin is deposited from the solution, so as to coat the iron with a dull uniform layer of metallic tin in about two hours. Whilst this is being done, a wrought-iron bath, containing fluid zinc, is being prepared, the melted metal is covered with *sal-ammoniac*, mixed with earthy matter, to lessen

the volatilisation of the sal-ammoniac, which becomes as fluid as treacle. Two iron rollers immersed below the surface of the zinc are fixed to the bath, and are driven by machinery to carry the plates through the fluid metal at a determined velocity. The plates are now received one by one from the tinning bath, drained for a short time, and passed at once, still wet, through the zinc by means of rollers; the plates thus take a regular and smooth layer of zinc, which, owing to the presence of tin beneath, assumes the natural crystalline character, giving the plates the well-known *moiré* appearance."

The following is another process, as described in the article from which we have taken the above:—"The iron articles to be galvanised are first cleaned and scoured by immersion in a bath of water, acidulated with sulphuric acid, heated in a leaden vessel, or used cold in a wooden one, just to remove the oxide. The pieces are then thrown into cold water, and taken out one at a time, to be scoured with sand and water, with a piece of cork or the husk of the cocoa-nut, the ends of the fibres serving as a brush. The pieces are then returned to cold water. Pure zinc, covered with a thick layer of sal-ammoniac, is then melted in a bath, and the iron, if in sheets, is dipped, several sheets at a



time, in a cradle or grating. The sheets are raised slowly to allow of draining—are then immediately thrown into cold water; on removal, the job is finished by wiping dry. Thick pieces are heated in a reverberatory furnace before being placed in the bath, to prevent cooling the zinc. Chains are similarly treated, and on removal from the zinc are shaken until cold, to avoid soldering of the links together. Nails and small articles are dipped in muriatic acid, and dried in a reverberatory furnace; next, thrown into zinc covered with sal-ammoniac, left for a minute, and taken out slowly with an iron skimmer. They come out in a mass soldered together, and, to separate them, are placed in a crucible surrounded with charcoal powder, then heated to redness, and shaken about until cold for separation. Wire is reeled through the zinc, into which it is forced to dip by a fork or other contrivance.

“The zinc is melted in a crucible just a little beyond the point of fusion, and is always covered with a thick coat of sal-ammoniac, for the purposes of preventing waste of zinc and preparing the metal to be covered. Wrought-iron baths welded at the angles succeed much better than cast-iron lined with clay. The spoiled granulated metal, which contains only about

five per cent. of iron, is refined by the proper persons, and returned for use at a small figure."

(35.) ALLOYS.—The alloy most used in construction is *brass*, which is an alloy of copper and zinc. The proportions of the best brass are, $63\frac{1}{2}$ parts of copper, and 32 1-5th of zinc. Brass or hard solder is composed of two parts of brass, with one of zinc, and a small portion of tin. Gun metal is an alloy—of copper 91 parts, and of tin 9 parts. Bell metal is composed—of copper 78, tin 22. The following is a table of the composition of what are called "commercial brasses," with their relative degrees of hardness, as estimated by MM. Crace Calvert and R. Johnson :—

Commercial Brasses.		Weight Employed.	Cast Iron = 1000. Obtained. | Calculated.	
		lbs.		
"Large Bearing,"	{ Copper, 82.05 *Tin, 12.82 Zinc, 5.13	2700	562	259
"Mud Plugs,"	{ Copper, 80 *Tin, 10 Zinc, 10	3800	750	262
"Yellow Brass,"	{ Copper, 64 Zinc, 36	2500	520	253
"Pumps and Pipes,"	{ Copper, 80.0 *Tin, 5.0 Zinc, 7.5 Lead, 7.5	1650	343	257

Bronze is an alloy of copper and tin, the proportions being varied according to circumstances. A bronze alloy of 21.21 of copper and of 78.79 of tin is not

brittle, while one of copper 39·98 and of tin 65·82 is brittle. An alloy as hard as iron, and not brittle, consists of as high a percentage of copper as 84·68, the proportion of tin being 15·32. Pewter is an alloy of lead and tin, of which the following is the hardest :—lead, 26·03 ; tin, 73·97 : the softest lead, 89·80 ; tin, 10·20. An alloy much used for lining bushes or journal boxes with, is thus described by the inventor :—

“First melt 4 oz. copper, and while melted add by degrees 12 oz. best quality Bancu tin; then add 8 oz. regulus antimony, then 12 oz. more tin. After the copper is melted, and 4 or 5 lbs. tin have been added, the heat should be reduced to a dull red colour, in order to prevent oxidation ; then add the remainder of the metals as above named. In melting the above there should be a small quantity of powdered charcoal upon the surface of the metal. I make the above-named composition (which I call hardening) in the first place ; then, as I want to use lining metal, add 21 lbs. of Bancu tin to every 1 lb. of hardening. This will produce the metal I now use for lining boxes. I find by experience that this is the best composition I have ever used ; so that the proportions for lining metal should be 4 lbs. copper, 8 oz. regulus antimony, and 96 lbs. *tin*.

“There is economy in first preparing the hardening. There will be less loss by oxidation, as the hardening can be melted at a less temperature than either the copper or antimony separately.

“As there will be some loss by oxidation in using the lining metal, I skim off the oxide and save it. When a quantity is saved, I put it into a crucible with fine charcoal, and expose it to a smart red heat, which will restore it to a metallic state. Add sufficient tin to make it look like the regular lining metal, and use it in lining.

“The box or article to be lined having been cast with a recess for the soft metal, is to be fitted to an iron, formed of the shape and size of the bearing or journal, allowing a little in size for shrinkage; drill a hole for the reception of the soft metal,—say from one-half to three-fourths of an inch diameter. The box having been thus prepared, wash the parts not to be tinned with a clay wash, to prevent the adhesion of the tin; wet the part to be tinned with alcohol, and sprinkle sal-ammoniac upon it; heat the box till a fume arises from the ammonia, and immerse it in a kettle of Bancu tin, care being taken to prevent oxidation. When sufficiently tinned, the box should be *soaked in water*, to take off any particles of ammonia.

that may remain upon it, as the ammonia would cause the metal to blow when poured into the box. Wash the former with fine pipe-clay, and dry it; then heat the box to the melting point of tin, wipe it clean and place it upon the former, and pour in the metal, giving it sufficient head as it cools. The box should then be scoured with fine sand, to take off any dirt that may remain upon it. It is then fit for use."

CHAPTER V.

MISCELLANEOUS NOTES CONNECTED WITH THE MANIPULATION OF METALS.

(36.) WE take, from a number of sources, a variety of notes and recipes connected with the metals used in construction, which are likely to be of practical use to the reader.

Annealing, Case-hardening, and Tempering of Iron and Steel.

1. ANNEALING OF METALS.—“In a considerable number of instances,” says the author of the “Mechanic’s Own Book,” “bodies which are capable of undergoing ignition, are rendered hard and brittle by sudden cooling. Glass, cast-iron, and steel, are the most remarkably affected by this circumstance,—the inconveniences arising from which are obviated by cooling them very gradually; and this process is called ‘annealing.’ Glass vessels are carried into an oven.

over the great furnace called the leer, where they are permitted to cool in a greater or less time, according to their thickness and bulk. Steel is most effectually annealed by making it red-hot in a charcoal fire, which must completely cover it, and be allowed to go out of its own accord. Cast-iron, which may require to be annealed in too large a quantity to render the expense of charcoal very agreeable, may be heated in a cinder fire, which must completely envelope and defend the pieces from the air till they are cold. The fire need not be urged so as to produce more than a red heat; a little beyond this, bars and thin pieces would bend, if destitute of a solid support, and would even be melted without any vehement degree of heat. If it be required to anneal a number of pieces expeditiously, and the fire is not large enough to take more than one or two of them at once, or if it be thought hazardous to leave the fire to itself, from an apprehension that the heat might increase too much, the following scheme may be adopted:—Heat as many of the pieces at once as may be convenient, and, as soon as they are red-hot, bury them in the dry sawdust. Cast-iron, when annealed, is less liable to warp by a subsequent partial exposure to moderate degrees of heat than that which has not undergone this operation.

"The above methods of annealing render cast-iron easy to work, but do not deprive it of its natural character. Cast-iron cutlery is, therefore, stratified with some substance containing oxygen, such as poor iron ores, free from sulphur, and kept in a state little short of fusion for twenty-four hours. It is then found to possess a considerable degree of malleability, and is not unfit for several sorts of nails and edge-tools.

"Copper forms a remarkable exception to the general rule of annealing. This metal is actually made softer and more flexible by plunging it, when red-hot, into cold water, than by any other means. Gradually cooling produces a contrary effect."

"In annealing of steel," says the *Engineer*, "the same care is required in the heating of it as there is in heating of it for hardening, as over-heating the steel is as injurious in one case as in the other; and in the process of annealing some artists differ very much,—some approving of heating the steel and burying it in lime, some of heating it and burying it in cast-iron borings; others approve of heating it and burying it in sawdust; but a far better plan is to put the steel into a box made for the purpose, and fill it with dust charcoal, and plug the ends up so that the air is kept from the steel, then to put

the box and its contents into the fire, till it is heated thoroughly through, and the steel a low red heat: it must then be taken from the fire, and allowed to remain in the box, without opening the box till the steel is cold; and, when taken out, the steel will be nice and clean, and very soft."

2. CASE-HARDENING OF IRON WITH ARSENIC.—

"Rasped leather or horn is mixed with a solution of arsenious acid, dissolved in hydrochloric acid to the consistency of common porridge. The metal to be hardened is painted over with this mixture to the thickness of $\frac{1}{16}$ in. On then heating the metal to bright redness, in a muffle or iron cylinder, a white surface of arsenide of iron is produced, of great hardness, and rust proof. This is given upon the authority of Mr Ekman, a Swede, but some partial experiments by Dr Percy do not quite confirm the value of the process. Some of the Turkish cast-iron cannon-balls contain a notable proportion of arsenic, and they are brittle in consequence.

"Put the articles to be case-hardened, after being finished but not polished, into an iron box in layers with animal carbon,—that is, horns, hoofs, skins, or leather, partly burned, so as to be capable of being reduced to powder,—taking care that every part of the iron is *completely* surrounded; make the box tight

with a lute of sand and clay, in equal parts ; put the whole into the fire, and keep it at a light red heat for half-an-hour to two hours, according to the depth of hardened surface required ; then empty the contents of the box into water, care being taken that any articles liable to buckle be put in separately and carefully, end in first. Cast-iron may be case-hardened as follows :—Bring the article to a red heat, and roll it in a mixture of powdered prussiate of potash, saltpetre, and sal-ammoniac, in equal parts ; then plunge it in a bath containing 2 oz. prussiate of potash and 4 oz. sal-ammoniac per gallon of water.

“ A simple method of case-hardening small cast-iron work is to make a mixture of equal parts of pulverised prussiate of potash, saltpetre, and sal-ammoniac. The articles must be heated to a dull red, then rolled in this powder, and afterwards plunged into a bath of 4 oz. of sal-ammoniac and 2 oz. of the prussiate of potash dissolved in a gallon of water.”

3. STEEL TEMPERING.—“The workmen judge of the amount of heat to be employed in tempering for various purposes by the colour of the metal. After the article is completed, it is heated slowly to a bright red ; it is then plunged into cold water ; this renders it hard ; *it is now tempered* by being again gradually warmed,

assuming various colours as it reaches various degrees of temperature, and again plunged into cold water. At a temperature of 430 degrees the metal is of a pale straw colour, at 500 degrees of a brownish yellow, at 520 degrees slightly purple, at 550 degrees dark purple, and at 600 degrees it is of a dark blue colour."

4. IRON CEMENT.—"To make an iron cement suitable for making rust joints, mix thoroughly 112 lbs. of clean cast-iron borings or turnings, with 8 oz. of sal-ammoniac and 1 oz. of flour of sulphur, and add sufficient water. Keep wet when not to be immediately used, or it will heat and be spoiled."

5. BRAZING OF STEEL.—"Silver, 19 parts; copper, 1 part; brass, 2 parts. If practicable, charcoal-dust should be strewed over the melted metal in the crucible."

6. BRAZING OF IRON AND BRASS.—"Iron and brass must be united by spelter, which is equal parts of brass and zinc. When the joints are cleaned and wired together, fine powdered borax is applied to them as a flux. The solder is then dusted on in the form of a powder, or fine filings, and melted in, either with a blow-pipe or by being placed in a charcoal fire. Care must be taken not to melt the brass to be brazed. The *solder*, of course, has a much lower fusion point than

the metals to be joined, else they would both run at the same time."

7. BRONZING OF METALS.—We take the following notes from the *English Mechanic*, a cheap and well-conducted London weekly periodical, which abounds in notes and recipes, useful in the daily work of the operative mechanic :—

"*Copper* articles may be bronzed by the following process :—Dissolve in vinegar 2 parts verdigris and 1 part sal-ammoniac. Boil, skim, and dilute with water, until white precipitate ceases to fall. Set in a pan meanwhile the articles to be bronzed, made perfectly free from grease, and clean. Boil solution briskly, and pour over the articles in the pan, and boil them briskly. A reddish-brown colour, bright, is thus acquired ; but the articles should be frequently inspected, and removed as quickly as the desired shade is obtained. Then they are to be repeatedly washed and dried. The solution must not be too strong, for then the bronze will come off by friction, or turn green on exposure to the air. But the best bronze for copper is that used by tea-urn makers and medallists. Long practice is an essential in this, and even the weather has to be consulted,—a westerly-wind day is the best. *The essentials* are a good description of the preparation

of iron used, free from grit, and mixed in water that has been boiled clean and clear to the thickness of cream ; next, a good clear coke fire, in which there is neither sulphur nor remnant of tin. The coke must be broken small, and a few knobs of coal ready at hand, with which, at a certain stage of the bronzing, to get up a steady, roaring flame. The copper article being ready, the surface is coated with the red cream, and then held over the roaring fire, turned round and round so as to place all parts in contact as soon and as often as possible. Practice and the size of the article here act as guides—the rest is as nothing without it. Some catch the ‘knack’ in a short time, others never. We have given the essentials, and than the last recipe for the vase there is none better. But the labour over the fire is ‘some,’ including the brushing up of the articles thereafter.”

“*Black Bronze for Brass.*—Put $3\frac{1}{2}$ lbs. of scales that fall from the red iron hammered at the blacksmith’s anvil, into 7 lbs. spirits of salts, and both into an earthenware pan, in which let them stand for about five hours, covered close to keep in the fumes ; stir it three or four times ; strain off into a stone bottle, into which put $1\frac{1}{2}$ lb. of white powdered arsenic ; shake well, let it stand for a day or two, and the mixture is

ready for use. Before using, cleanse the brass from grease either with emery-cloth or a brush, with sand and plenty of water. Next dip the brass in the bronze until it is black, then wash it in clean water, then in boiling water ; for thus heat is given to dry the work and preserve the bronze. A soft blacklead brush is then applied with some good lead, then the article is to be lacquered with a very pale lacquer, and heated in an oven or on a hot plate to set it hard. For green do the same work with green lacquer for brass, to be had in any colour-shop at about one shilling a gill. To make iron green, cleanse it first from grease, then give it a coat of blacklead, next one of green lacquer, then make the article hot in an oven or on a plate, put on another coat of lacquer, and heat finally."

"*Black-Bronzing Iron and Steel.*—This method of colouring iron and steel to serve both as an ornamentation and preservative from rust is the discovery of M. Thirault, and has been successfully adopted in many factories. The following mixtures are not the only ones that can be employed, but are given as examples:—

"Liquid, No. 1.—A mixture of bi-chloride of mercury, and sal-ammoniac.

"Liquid, No. 2.—A mixture of perchloride of iron, sulphate of copper, nitric-acid, alcohol, and water.

“Liquid, No. 3.—Perchloride and protochloride of mercury, mixed with nitric-acid, alcohol, and water.

“Liquid, No. 4.—A weak solution of sulphide of potassium. A sponge is slightly moistened with liquid No. 1, and rubbed upon the metal, previously well cleaned, and when quite dry, a second application of the liquid is made; the crust of oxide formed upon the application of the liquid is removed by a wire brush, and the metal rubbed with a clean piece of rag, and this operation is repeated after every fresh application of the several liquids.

“Several coats of liquid No. 2 are then applied, and also of No. 3, with a full sponge; and after drying for ten minutes, the pieces of metal are thrown into water heated nearly to the boiling point, where they are allowed to remain five or ten minutes, according to their size. After being cleaned, they are again covered with several coatings of liquid No. 3, afterwards with a strong coating of No. 4, and again immersed in the bath of hot water. When removed from the bath, the pieces are dried and wiped several times with carded cotton, dipped in liquid No. 3, diluted each time with an increased quantity of water; then they are rubbed with a little olive oil and wiped. They are again immersed in water heated to 140° F., and upon being

removed from it, they are rubbed briskly with a woollen rag, and lastly with oil.

"The pieces thus treated are of a beautiful glossy black, especially if they have been polished.

"Iron and cemented steel are well adapted to receive this black polish. Cast-steel is still better adapted for it, as it assumes a more uniform brilliancy. Cast-iron presents more difficulties, because it does not assume the same tint all over equally."

"Two kinds of bronze are used for brass, for common work, gasfittings, etc. Mix vinegar or dilute sulphuric acid (one acid 12 water) with powdered blacklead, in a saucer or open vessel; apply this to the brass with a soft plate-brush by gentle brushing. This will soon assume a polish, and is fit for lacquering. The brass must be made slightly warmer than for lacquering only. A little practice will enable the operator to bronze and lacquer with one heating. The colour, black or green, varies with the thickness of blacklead.

8. PRESERVATION OF IRON FROM RUST.—*A mixture for coating bright ironwork to prevent rusting:—"Common rosin, melted with a little gallipoli oil and spirits of turpentine, is applied in such a state of consistency that it will not easily chip off, although it may be removed by careful scraping. This coating is pro-*

nounced to be more effective than white lead and tallow."

On this subject the following notes from *The Mechanic's Magazine* will be useful:— "The means to be adopted to counteract the formation of rust may be classed into—(1.) A choice as to the nature of the iron ; (2.) the use of galvanism ; (3.) the employment of protective coatings. To insure comparative freedom from rust, cast-iron should be uniform, bright, and hard. Generally speaking, wrought-iron suffers nearly three times as much as common cast-iron from corrosion ; spiegeleisen, on the other hand, scarcely at all. Speaking of the nature of the iron, we may mention here that Mr M. Poole took out a patent in 1845 for making iron hard, durable, and free from oxidation, by employing ferrocyanide of sodium, barium, calcium, or other alkalies or alkaline bases, in the manufacture.

"The use of galvanism is based upon the phenomenon that it is the electro-positive substance which is first oxidised. Zinc, being very electro-positive to iron, is the metal most employed for diverting the oxygen from the iron to itself. Tin is much less electro-positive, and iron is tinned rather to give it a durable coating than for any galvanic purpose. Copper is electro-negative to iron, and if used galvanically would actually accelerate rust-


ing. If brass be employed, the proportion of copper in it must not therefore be more than 31 per cent. Unfortunately, the preservative action ceases as soon as the zinc becomes covered with zinc-oxide. Iron coated with zinc, and lying in sea water, or even in some fresh waters, gets also soon covered with carbonate of lime, which stops the protection and enables marine animals and plants to attach themselves.

“The third and most general means for preserving iron from rust, is coating the surface with some kind of protective layer. The commonest coatings in use are paints, pitch, tar, oil, and grease, and in some of these cases the iron is either hot at the time of application, or is else heated afterwards. But paint containing red-lead must be carefully eschewed, as it directly accelerates rusting by imparting to the iron its own oxygen, and thus changing, according to Jouvin, in course of time, actually into metallic lead. Asphalte alone, or shellac dissolved in methylated or wood spirit, insoluble soaps, and solutions of india-rubber, are occasionally employed. Vogel suggests a coating of white wax dissolved in benzine, the latter evaporating and leaving a thin skin of wax. M. Thiebault, of St Etienne, recommends a covering of black oxide, which *is produced by rust formed artificially on the surface,—*

the iron being then plunged into nearly boiling water. This process having been repeated several times, the exterior is covered with a weak solution of sulphate of potash, and finally rubbed over with olive oil. By this process the rust loses its affinity for oxygen, and does not form a voltaic pile with the iron. Some of the patents taken out in England for giving the iron a protective coating are worth notice. In 1849, Mr Paris patented a process, according to which a solution of gum was spread over the cleansed surface of the iron, powdered glass being strewn upon it, and then fused. In 1856, Mr Reid, a mineralogist, took out a patent for what he called a sure method. As far as simplicity and cheapness are concerned, it would seem to leave nothing to be desired. The iron is first placed in a furnace and covered with soot. The temperature is then raised to red or white heat, and the iron having been cooled down and cleaned, a coat impervious to rust is said to be formed. In the same year, Mr Atkinson patented the depositing of brass or copper on iron, a process said to be successfully carried out at Portsmouth, by Mr Wielan, on armour-plates. In 1858, Messrs Bouchard and Clavel, Paris bankers, patented a paint chiefly containing an ochre found on an estate in the Departement de l'Yonne. This peculiar kind of

ochre, called Burgundy red, is said to possess some excellent qualities, and to be also an exceedingly good preservative against rust.

“There are still some rust-preventing substances which cannot well be included amongst the coatings—alkalies, for instance. Iron may be safely kept in lime-water, or water containing either carbonate of soda or potash. Payen gives as a reason that the contact with them renders the iron electro-negative. For protecting iron kitchen-utensils when out of use, a paste of soda, roasted starch, and water, would be much better than grease, which turns rancid, and then quickly leads to the formation of rust. The presence of slaked lime, and especially chloride of lime, in the neighbourhood of polished steel, is also very effective in preserving it from corrosion, as both these earths have a strong affinity for carbonic acid and water. Herr Krupp's cases of steel, in the last great Exhibition, were provided with pieces of chloride of lime placed in a saucer, and it was remarkable in how bright a state the fractured surfaces were kept by this means. Charcoal powder is much more useful than sawdust for packing up iron-ware, as wood in a minute state of subdivision has its hygroscopic properties, or affinity for moisture, greatly increased.”



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